RELATIONSHIP BETWEEN SOIL SALINITY AND CHLORIDE CONTENT IN GROUNDWATER IN SALINE SOIL AREAS OF NAKHON RATCHASIMA PROVINCE

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Civil, Transportation and Geo-resources

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ความสัมพันธ์ระหว่างความเค็มของดินกับปริมาณคลอไรด์ในน้ำบาดาลบริเวณพื้นที่ดินเค็มของจังหวัดนครราชสีมา

นางสาววรรณิดา ทองวัฒน์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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วรรณิดา ทองวัฒน์ : ความสัมพันธ์ระหว่างความเค็มของดินกับปริมาณคลอไรด์ในน้ำบาดาลบริเวณพื้นที่ดินเค็มจังหวัดนครราชสีมา (RELATIONSHIP BETWEEN SOIL SALINITY AND CHLORIDE CONTENT IN GROUNDWATER IN SALINE SOIL AREAS OF NAKHON RATCHASIMA PROVINCE) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.บัณฑิตา ธีระกุลสถิตย์, 161 หน้า.

งานวิจัยชิ้นนี้มีจุดมุ่งหมายหลักเพื่อศึกษาความสัมพันธ์ระหว่าง ค่าความเค็ม กับปริมาณคลอไรด์ ในตัวอย่างดิน น้ำบาดาล และ น้ำผิวดิน ในบริเวณพื้นที่ดินเค็มในจังหวัดนครราชสีมา มีขอบเขตครอบคลุม อำเภอโนนแดง อำเภอโนนไทย อำเภอโนนสูง อำเภอคง และอำเภอขามสะแกแสง จำนวนตัวอย่างที่เก็บทั้งหมดประกอบด้วย ตัวอย่างดิน 50 ตัวอย่าง ตัวอย่างน้ำบาดาล 57 ตัวอย่าง และ น้ำผิวดิน 14 ตัวอย่าง ที่เก็บในฤดูฝน (เดือนตุลาคม พ.ศ. 2560) และ ตัวอย่างดิน 50 ตัวอย่าง ตัวอย่างน้ำบาดาล 57 ตัวอย่าง และ น้ำผิวดิน 14 ตัวอย่าง ที่เก็บในฤดูแล้ง (เดือนพฤษภาคม พ.ศ. 2561) ได้ทำการวัดค่าคุณสมบัติทางเคมี ของตัวอย่างทั้งหมด ณ ตำแหน่งที่เก็บทันทีประกอบด้วย การวัดค่าความเป็นกรด-ด่าง (pH) ค่าการนำไฟฟ้า (EC) ค่าปริมาณของของแข็งที่ละลายอยู่ในน้ำ (TDS) ค่าความเค็ม ส่วนการวิเคราะห์ปริมาณคลอไรด์ได้ทำโดยวิธีการไตเตรทในห้องทดลองของมหาวิทยาลัยเทคโนโลยีสุรนารี การวัดปริมาณองค์ประกอบของแร่ และปริมาณองค์ประกอบของโลหะออกไซด์ดำเนินการโดยเครื่อง X-ray diffraction spectrometer (XRD) และ X-ray fluorescence spectrometer (XRF) ตามลำดับ องค์ประกอบของธาตุ แคลเซียม แมกนีเซียม โปแทสเซียม เหล็ก และ โซเดียม วิเคราะห์โดย Flame Atomic Absorption Spectrometer Analysis (FAAS) ได้แสดงผลวิเคราะห์ในรูปแบบของกราฟเส้นของค่าผลวิเคราะห์ที่พล็อตลงเส้นแกนของตำแหน่งการเก็บตัวอย่าง พบว่าค่าความเข้มข้นทางเคมีของตัวอย่างที่เก็บในฤดูแล้งมีค่าสูงกว่าค่าความเข้มข้นทางเคมีของตัวอย่างที่เก็บในฤดูฝน ความสัมพันธ์ระหว่างปริมาณความเค็มและปริมาณคลอไรด์ในตัวอย่างดิน น้ำบาดาล และน้ำผิวดิน ถูกนำเสนอในรูปแบบของแผนที่การกระจายตัวของค่าความเข้มข้น โดยอาศัยโปรแกรมคอมพิวเตอร์ Arc Map 10.3 จากการประเมินแผนที่การกระจายตัวของค่าความเข้มข้น พบว่าตัวการที่ควบคุมปริมาณค่าความเค็ม และปริมาณคลอไรด์ใน ดิน น้ำบาดาล และน้ำผิวดิน คือ ฤดูกาล ความสูงของพื้นที่และระดับน้ำบาดาล ดังนั้น พื้นที่ต่ำที่มีระดับผิวดินน้อยกว่า 170 เมตร เช่น พื้นที่ในอำเภอโนนสูงตอนใต้ของอำเภอคง และ อำเภอโนนแดง จะมีระดับน้ำบาดาลตื้น น้ำบาดาลก็มีโอกาสที่จะซึมขึ้นสู่ผิวดิน เมื่อระเหยก็จะทิ้งคราบเกลือทำให้เกิดดินเค็ม

สาขาวิชา เทคโนโลยีธรณี ลายมือชื่อนักศึกษา วรรณิดา

ปีการศึกษา 2561 ลายมือชื่ออาจารย์ที่ปรึกษา บัณฑิตา ธีระกุลสถิตย์

WANNIDA THONGWAT : RELATIONSHIP BETWEEN SOIL SALINITY AND CHLORIDE CONTENT IN GROUNDWATER IN SALINE SOIL AREAS OF NAKHON RATCHASIMA PROVINCE. THESIS ADVISOR : ASST. PROF. BANTITA TERAKULSATIT, Ph.D., 161 PP.

GROUNDWATER/HYDROGEOLOGY/SOIL SALINITY/GEOCHEMISTRY

The main purpose of this research is to study relationship between soil salinity and chloride content in soil, groundwater and surface water samples within saline soil areas of Nakhon Ratchasima Province, covering Non Daeng, Non Thai, Non Sung, Kong, and Kham Sakae Saeng districts. Total of 50 soil, 57 groundwater, and 14 surface water samples were collected during rainy season (October 2017). And other 50 soil, 57 groundwater, and 14 surface water samples were collected in dry season (May 2018). Measuring of pH, electrical conductivity (EC), total dissolved solids (TDS), salinity contents of all sample types were done directly at the sampling sites. Chloride contents were determined by titration method in Suranaree University of Technology's central laboratory. Mineral compositions and metal oxide contents were determined by X-ray diffraction spectrometer (XRD) and X-ray fluorescence spectrometer (XRF), respectively. Compositions of calcium, magnesium, potassium, iron and sodium ions were determined by Flame Atomic Absorption Spectrometer Analysis (FAAS). The results of analyses were subsequently displayed by graphic presentation of chemical contents against sampling sites. Analytical results showed that chemical contents of samples collected in dry season are higher than samples from rainy season. Relationship between values of salinity and chloride contents in soil, groundwater and surface water samples were displayed as distribution maps,

made by Arc Map 10.3 computer program. The distribution maps demonstrated that seasons, elevation of topography, and groundwater level are factors, controlling values of chloride contents, and salinity contents. Low-lying (MSL less than 170 meters) areas, i.e. Non Sung, southern part of Khong and Non Daeng, shallow groundwater level areas are locations that transported saline groundwater seeps out and deposits salt on ground surface.

School of Geotechnology

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Student's Signature Wannida

Advisor's Signature Bantita

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I would also like to extend my thanks to the technicians of the laboratory for their help in offering me the resources in running the program.

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Wannida Thongwat

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SYMBOLS AND ABBREVIATIONS

us/cm	=	micro-siemens per centimeter
mg/l	=	milligram per litter
ppm	=	parts per million
ppt	=	parts per trillion
wt%	=	percent by weight
msl	=	mean sea level

CHAPTER I

INTRODUCTION

1.1 Rationale and background

Saline soils refer to soils that contain high value of soluble salts, indicated by electrical conductivity of the saturation soil extract of more than 4,000 us/cm at 25°C (Richards, 1954). Soluble salts are most commonly composed of chlorides and sulfates of sodium, calcium, and magnesium. Especially, sodium and chloride are the most dominant ions, particularly in highly saline soils. The salt-affected soils in Thailand can be classified according to their origins into two types, consisting of coastal saline soils (found along the coast where tide can reach or previously inundated by sea) and salt-affected soils on land (found mostly in low areas and the shoulders of mounds in the Northeastern part of Thailand). Saline soils were found in almost every province of the Northeast, which covers an area of 17.8 million rai. Soil salinity tends to spread more covering other 19.4 million rai of land area.

The major constraints of agriculture include insufficient water, infertile soil, and soil salinity. Nakhon Ratchasima Province produces agricultural crops mainly rice, cassava, and sugar cane. These agricultural productions were harshly affected by spreading of soil salinity. Total saline soil area of about 3,424 square kilometers was recovered. Saline soil naturally occurs by dissolving of rock salts. Soluble salts later migrate to lowland, where groundwater table is very shallow (Ratanopad and Kainz, 2006). Deforestation is common in saline soil areas. During dry season, salt is interspersed to ground surface and leached away in the rainy season.

Rain water can cause contamination of groundwater by leaching of constituents down to groundwater level while flowing through sediments. Dissolved ions then accumulate until reaching toxic level. Sources of contaminant can be natural or man-made. Man-made sources are, e.g. effluent from private or municipal septic systems, and some agricultural chemicals etc. Natural sources include rock-water interactions, saline seeps, and minor atmospheric contributions. Salinity is a kind of groundwater contamination. When saline groundwater seeps through soil surface, accumulation of salt occurs. Especially in dry period, salt accumulation was found on the ground in several places (Davis et al., 1998). Saline groundwater is clearly a cause of saline soil in the Northeast of Thailand.

This study is therefore aimed at studying the relationship of salinity in soil, groundwater and surface water.

1.2 Research objective

The objective of this study is to determine the relationship of chemical properties between soil, groundwater and surface water. Distribution maps of salinity and chloride in soil, groundwater, and surface water samples were studied to find relationship among different chemical properties in various sample types and seasons.

1.3 Scope and limitation of the study

The study area covers five districts of Nakhon Ratchasima Province, including Non Thai, Non Sung, Non Daeng, Khong, and Kham Sakae Saeng Districts (Figure 1.1). Soil, groundwater, and surface water samples were collected during rainy season in October 2017, and summer season in May 2018. The content of pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity was measured. Chloride content was analyzed by Mohr's method. Mineral composition was analyzed by x-ray diffractometer (XRD). The analysis of major and trace elements was made by x-ray fluorescence (XRF). Elemental composition consisting of sodium and potassium was analyzed by flame atomic absorption spectroscopy (FAAS).

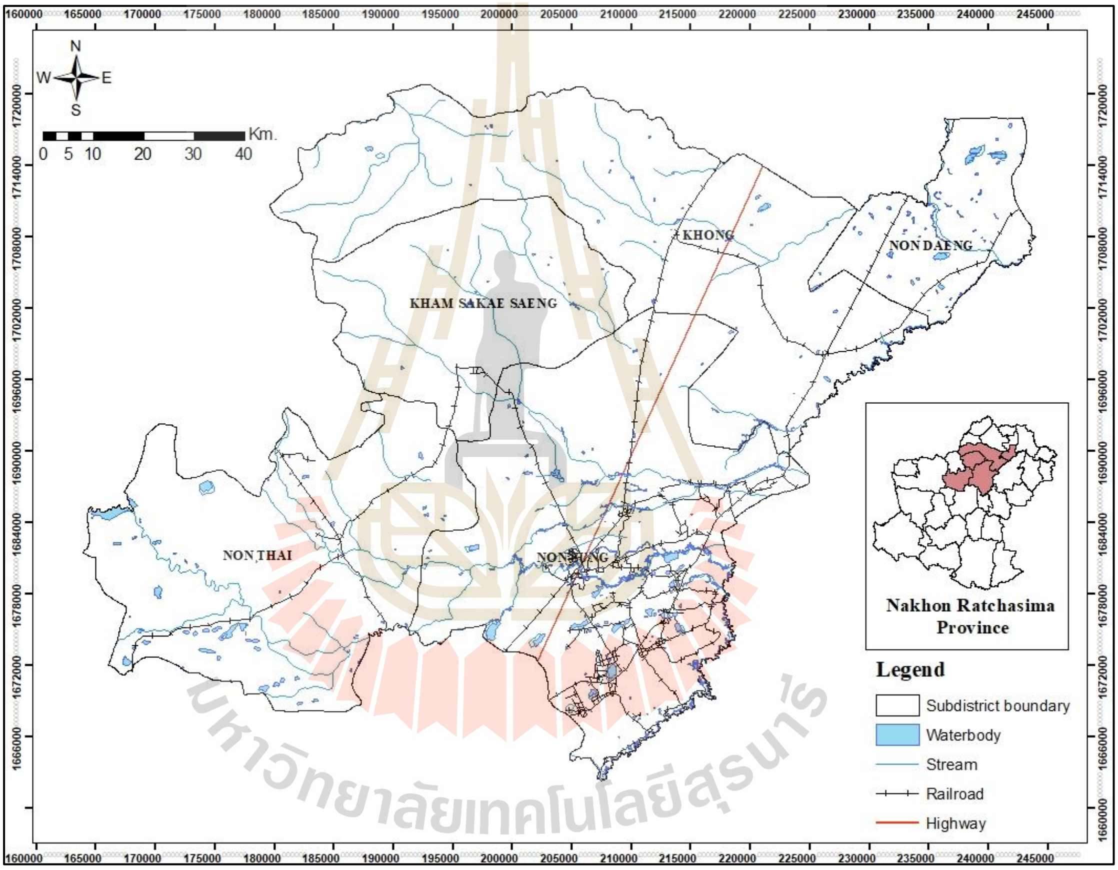


Figure 1.1 The study area in Nakhon Ratchasima Province.

Soil samples were taken from Dan Chak, Non Thai, and Sam Rong subdistricts of Non Thai District; Mai, Lum Khao, Bing, Than Prasat, and Don Chomphu subdistricts of Non Sung District; Don Yao Yai, Samphaniang, Wang Hin, and Non Ta Then subdistricts of Non Daeng District; Thephalai, Kham Sombun, Ta Chan, Khu

Khat, Mueang Khong, Ban Prang, and Nong Bua subdistricts of Khong District; and Mueang Kaset, Nong Hua Fan, Chiwuek, Kham Sakae Saeng, and Mueang Nat subdistricts of Kham Sakae Saeng District.

Groundwater samples were taken from Banlang, Sai O, Thanon Pho, and Makha subdistricts of Non Thai District; Lum Khao, Than Prasat, Dan Khla, Tanot, and Phon Sungkhram subdistricts of Non Sung District; Non Daeng, and Samphaniang subdistricts of Non Daeng District; Non Teng, Nong Manao, Mueang Khong, Ban Prang, and Nong Bua subdistricts of Khong District; and Non Mueang, Mueang Kaset, Nong Hua Fan, Chiwuek, Kham Sakae Saeng, and Mueang Nat subdistricts of Kham Sakae Saeng District.

Surface water samples were taken from Dan Chak, and Non Thai subdistricts of Non Thai District; Bing, Than Prasat, and Don Chomphu subdistricts of Non Sung District; Non Daeng, Don Yao Yai, and Samphaniang subdistricts of Non Daeng District; Kham Sombun, Khu Khat, and Mueang Khong subdistricts of Khong District; and Kham Sakae Saeng subdistricts of Kham Sakae Saeng District.

1.4Research methodology

Summary of research methodology was displayed in Figure 1.2. Working steps were briefly described as follows:

1.4.1 Literature review

Relevant literatures were studied, reviewed, and referred as references. The summary of the literature review included rock salt, hydrogeology, and soil salinity of Nakhon Ratchasima Province.

1.4.2 Samples of soil and water collection

Soil, groundwater, and surface water samples were collected during the rainy season, and dry season from Non Thai, Non Sung, Non Daeng, Khong and Kham Sakae Saeng Districts in Nakhon Ratchasima Province.

1.4.3 Sample Preparation and analysis

Soil samples were split and later prepared to be powder and solution samples suitably for different kinds of analyses. Analyses included pH, electrical conductivity (EC), total dissolved solids (TDS), salinity content, chloride content, mineral composition and elemental composition.

1.4.4 Data analysis and discussion

Analystical results, i.e. pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), salinity content, and chloride content, were compared in relation to rainy and dry season. Similarity and discrepancy of results had been discussed.

1.4.5 Conclusion and thesis writing

All research activities, method, and results were documented and compiled in this thesis.

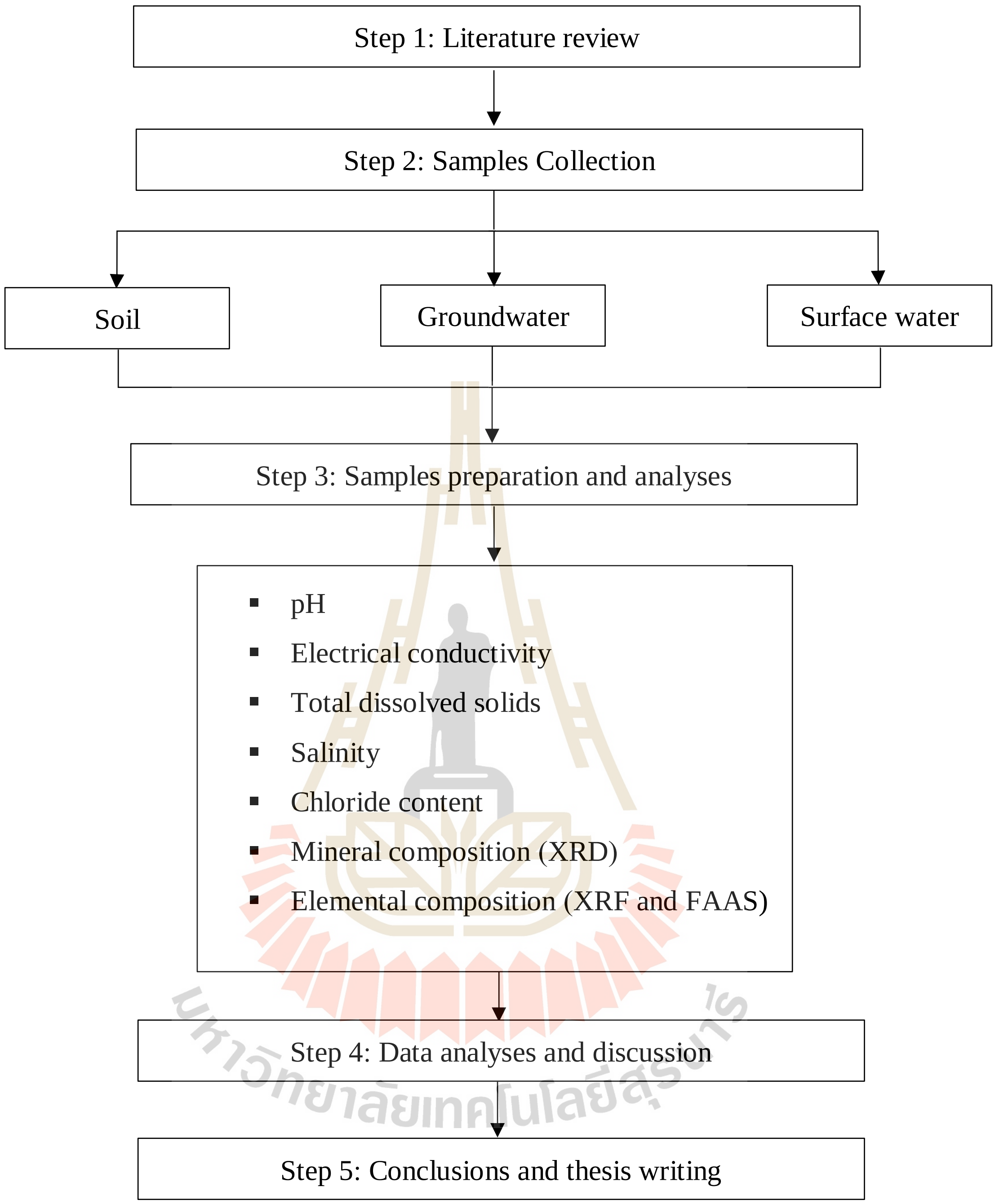


Figure 1.2 Diagram showing steps of research methodology.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Literature review concerns general geology, hydrogeology and saline soil in Nakhon Ratchasima Province, Thailand. Quality of soil, groundwater, and surface water, together with saline soil effect were also studied.

2.2 General geology

2.2.1 Khorat Plateau

Khorat Plateau of northeastern Thailand covers two a large evaporate basins of Cretaceous age, i.e. northern (Udon-Sakon Nakhon) basin and southern (Khorat-Ubol) basin. They were separated by a mountain range, called Phu Phan Range (Figure 2.1).

Khorat Plateau is defined by large area of Mesozoic era (mainly Cretaceous) continental sedimentary rocks of the Khorat Group. General Stratigraphy of the Udon-Sakon Nakhon Basin and the Khorat-Ubol Basin was illustrated in Figure 2.2 (Tabakh et al., 1999).

Khorat Group are divided to be Lower Khorat unit and Upper Khorat unit. The Lower Khorat unit consists of Huai Hin Lat Formation, Nam Phong Formation, Phu Kradung Formation, Phra Wihan Formation, Sao Khua Formation, Phu Phan Formation, and Khok Kruat Formation. The Upper Khorat unit consists of of Maha

Sarakham Formation and Phu Tok Formation (DGR, 2007). The rock formations were briefly described from lower to upper formations as follows.

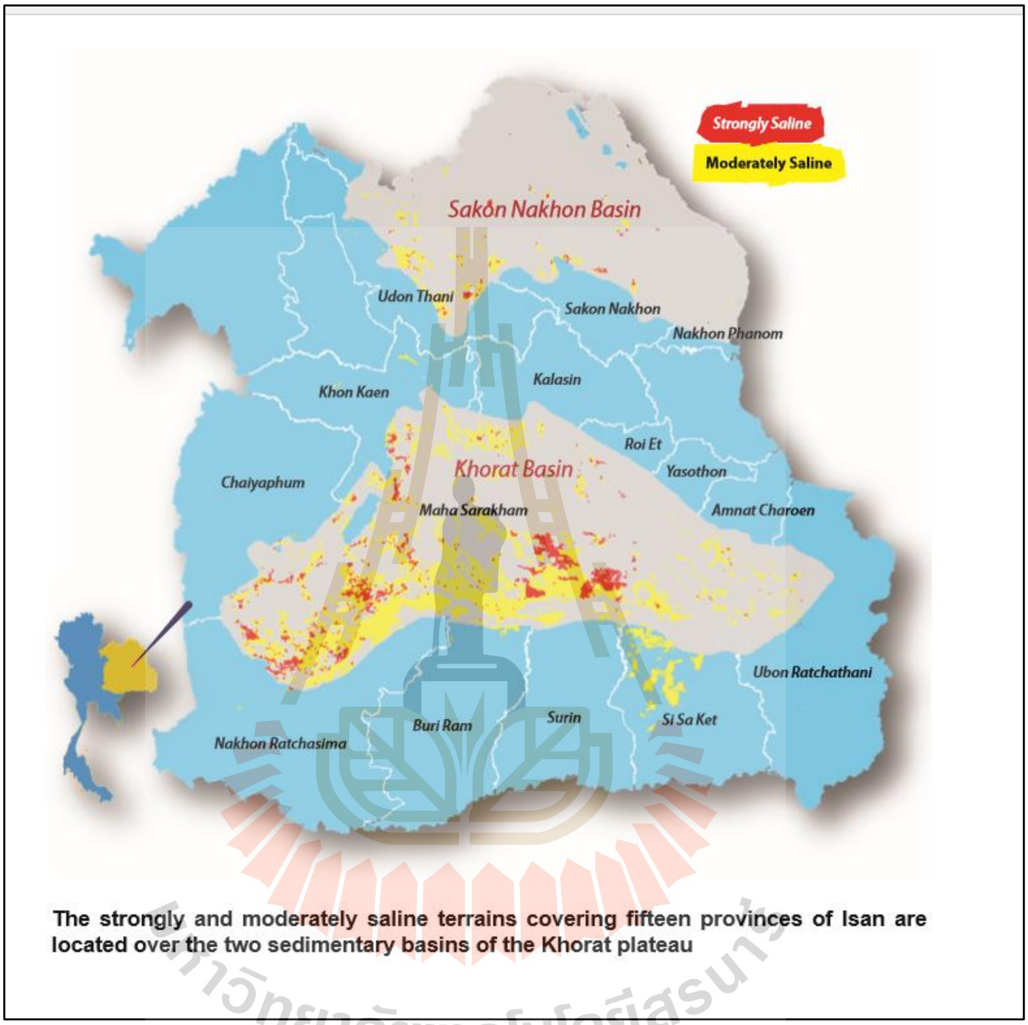


Figure 2.1 Generalized Geological Map of the Northeast of Thailand (DMR, 2015).

- Huai Hin Lat Formation: This lowest formation of the Khorat Group consists of conglomerate, limestone conglomerate, grey to dark grey sandstone, siltstone, black shale and marl containing plant fossils.
- Nam Phong Formation: It can be divided into two parts. The upper part consists predominantly of siltstone, minor sandstone, and claystone

together with thin limestone. Siltstone is dusky red to red-brown to purple, none to slightly calcareous, and commonly contains lithoclastic of claystone, limestone and quartz grains. The lower part consists of red-brown sandstone, siltstone, and claystone. The formation conformably overlies Huai Hin Lat formation. At some localities, it unconformably overlies Permian limestone.

- Phu Kradung Formation: This formation is consisted of interbedded sandstone and siltstone, with occasional limestone lenses and concretions and thin bed of claystone. Color of sandstone ranges from light grey, light to medium brown, red-brown, and medium green to off-white with varicolored grains.

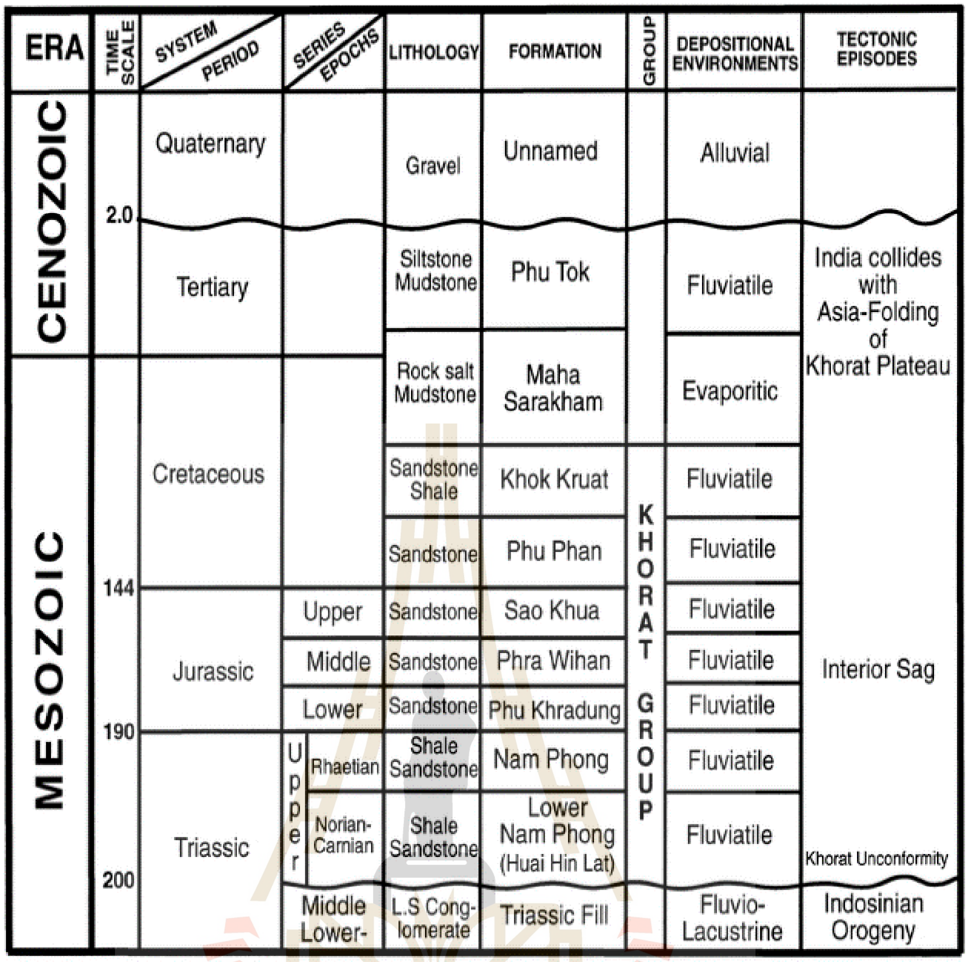


Figure 2.2 General Stratigraphy of the Udon-Sakon Nakhon Basin and the Khorat-Ubol Basin (Tabakh et al., 1999).

- Phra Wihan Formation: It consists of cross-bedded white quartz sandstone with thin bed of siltstone and occasionally of thin beds of claystone and nodular limestone. The sandstone is off-white to grayish green, fine to medium grained but locally coarse to very coarse-grained, with calcareous cement.

- Sao Khua Formation: This formation is consisted of interbedded sandstones and siltstones with minor claystone, with occasional nodular limestone occurrences towards the base.
- Phu Phan Formation: This formation is consisted of fine to medium-grained sandstone interbedded with siltstone. The sandstone is off-white to light grey, greyish-green, reddish brown, occasionally light brown, moderately hard, subangular, partly micaceous, with traces of siltstone and limestone lithoclasts.
- Khok Kruat Formation: This formation consists of interbedded sandstone, siltstone, and claystone. The sandstone is red to brown, very fine to medium grained and with fair to poorly visible porosity. The siltstone is red, hard, slightly very calcareous, commonly sandy, and grading to sandstone and nodules. The claystone is red to reddish brown, soft to moderately hard, non-calcareous, and commonly silty.
- Maha Sarakham Formation: It is present within the Northern Sakon Nakhon Basin and the Southern Khorat Basin. Thickness of the formation averages 250 meters thick at the type locality (Gardner et al., 1967). This formation overlies the Khok Kruat Formation with a very sharp boundary at the bottom of the basal anhydrite (Hite and Japakasetr, 1979). Lower, Middle and Upper salt members of this formation are main sources of soil and groundwater salinization in Khorat Plateau. Salt domes and salt anticline of the Maha Sarakham Formation occur in several places (Warren, 1999).

- Phu Tok Formation: This formation consists of massive red sandstone with very large cross-bedding, with interbedding of channelized fine-grained, red to purple sandstone and siltstone with red clay horizons.

2.2.2 Rock salt in Khorat Plateau

Khorat plateau covers two sedimentary basins, i.e. Sakon Nakhon Basin and Khorat Basin. Occurrences rock salt in these two basins are long known. Sakon Nakhon Basin in the north has an area of about 17,000 square kilometers. It covers the area of Nong Khai, Udon Thani, Sakon Nakhon, Nakhon Phanom, and Mukdahan provinces and extends to some part of Laos. Khorat Basin is in the south, which covers area of about 30,000 square kilometers. The basin covers the area of Nakhon Ratchasima, Chaiyaphum, Khon Kaen, Maha Sarakham, Roi Et, Kalasin, Yasothon, Ubon Ratchathani provinces and the north of Burirum, Surin, and Sisaket provinces (Suwanich, 1986).

Maha Sarakham Formation of Cretaceous to early Tertiary period is composed of three evaporitic successions, each overlain by non-marine clastic red beds, and are present in both the Khorat and the Sakon Nakhon basins. Evaporites include thick successions of halite, anhydrite and a considerable accumulation of potassic minerals (sylvite and carnallite) but contain some tachyhydrite and minor amounts of borates (Tabakh et al., 1999).

According to Yumuang (1983), Suwanich (1986) and Tabakh et al. (1999) the stratigraphy of the Maha Sarakham Formation can be summarized as follows:

(1) Basal Anhydrite Member (Thickness 0.75-6.20 meters)

The Basal Anhydrite Member is found at the base of Maha Sarakham Formation throughout both the Khorat and the Sakhon Nakhon Basins. It conformably overlies the Khok Kruat sandstone of the Khorat Group. The generally reddish-colored sandstone of the Khok Kruat Formation is typically greenish and maybe Cu-stained in proximity to this contact. Although in areas of slumping or dissolution, anhydrite layer locally varies in thickness from 0.75-6.20 meters. Mean thickness of 1.0 meter characterizes the unit across the regional extent of the Maha Sarakham evaporate in the basin.

(2) Lower Salt Member (Thickness 30-500 meters)

The Lower Salt Member is the most widespread of the salt units in the Maha Sarakham Formation. Halite with accessory anhydrite is the dominant mineral. However, a zone rich in potash minerals characteristically occurs near the top of the unit. A layer of depositional-textured anhydrite up to 3.45 meters in thickness separates the Lower Salt into upper and lower portions and can be correlated throughout the basin. The contact with the Basal Anhydrite is sharp, where contact with potash-rich zone is generally gradation.

(3) Lower Clastics Member (Thickness 10-60 meters)

The Lower Clastics Member comprises reddish brown claystone, invariably containing randomly oriented fractures filled with halite spar. The color of the claystone may be greenish-gray in the vicinity of the contacts with the underlying and overlying salt units.

(4) Middle Salt Member (Thickness 20-180 meters)

The Middle Salt Member comprises well-bedded halite with similar repetitive bed forms to those found in the upper part of the Lower salt. Rare sylvite and carnallite grains are occurring sporadically, and rarely a poorly developed potash zone may top the sequence.

(5) Middle Clastics Member (Thickness 20-70 meters)

The Middle Clastics Member consists of massive red to purple claystone and silty mudstone. Bedding in this unit is well defined with cryptalgal lamination and root traces.

(6) Upper Salt Member (Thickness up to 20 meters)

The Upper Salt Member is the least preserved halite member in the Khorat Basin because of later dissolution and possible non-deposition in some parts of the basin, However, these salt beds, when observed, are the least deformed beds in the sequence.

(7) Upper Clastics Member (Thickness up to 687 meters)

The Upper Clastics Member consists of pale reddish-brown silty claystone with minor sandy intervals. In this unit, bedding is well defined and even lamination, root traces, and sets of cross beds are commonly observed. The unit generally exhibits upward coarsening. The contact with the overlying Phu Thok Formation is not defined. The general lithostratigraphy and subdivisions of the Khorat Group and the Maha Sarakham Formation are simplified and shown in Figure 2.3.

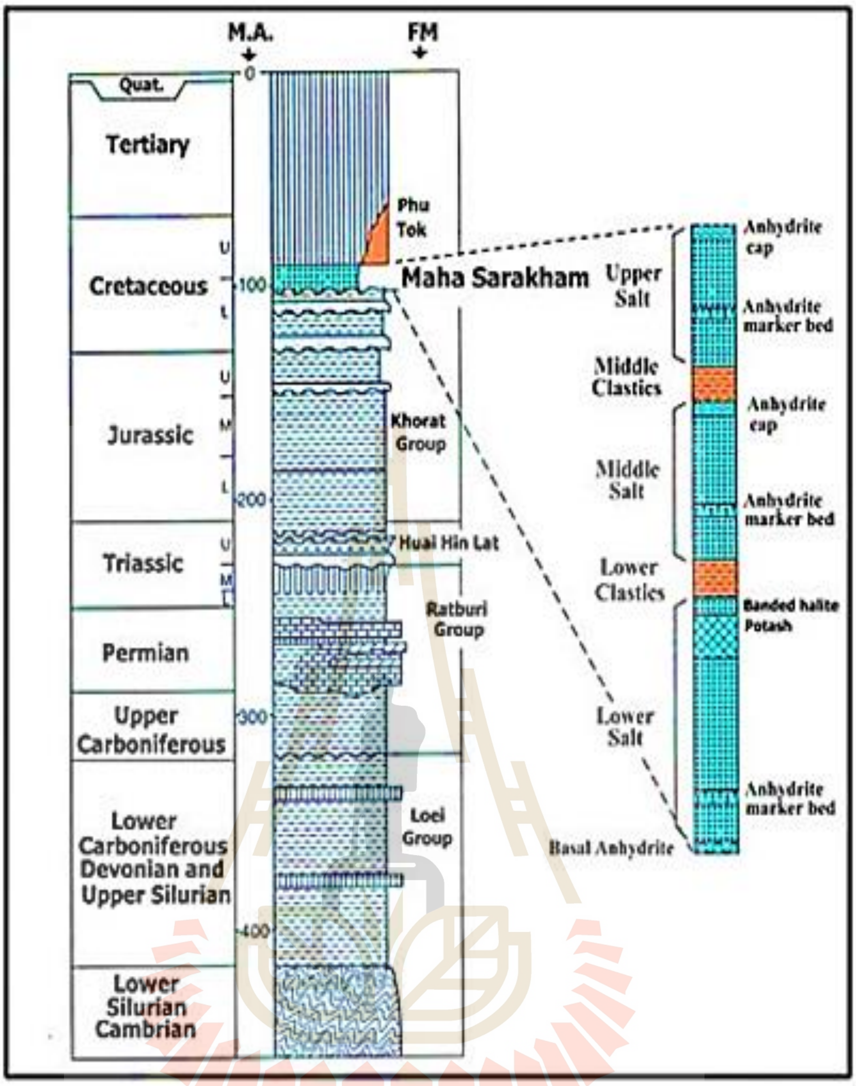


Figure 2.3 Lithostratigraphy and subdivisions of the Khorat Group and the Maha Sarakham Formation (modified after Suwanich, 1986).

2.3 Hydrogeology

Groundwater is an important source of consumable water in Thailand Over 70 percent of groundwater is used for agriculture. The main problems concerning water in Thailand are pollution, floods and drought. The problems vary depending on the geographical zone (Fornés and Pirarai, 2014). Groundwater is the water present beneath

Earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit, containing groundwater is called an aquifer. Aquifers are typically made up of gravel, sand, sandstone, or fractured rock, like limestone. Water can move through these materials because they have large connected spaces that make them permeable. Groundwater can be found almost everywhere. The water table may be deep or shallow and may rise or fall depending on many factors. Groundwater can be recharge through rock fractures and pores of rock. The sediment cover in this area is predominantly sandy which also enhances recharge (Dissataporn, 2002). The rainwater recharged to groundwater in high topographic areas flows by gravity to the low-lying areas, and groundwater can also be recharged by surface water in reservoir and irrigation systems. Many large reservoirs have been constructed by blocking the rivers in Khorat Plateau, e.g. Lum Takhong, Lum Chiang Krai, and Lum Phra Phlueng Mun, and Chi rivers.

2.3.1 Hydrogeology of Nakhon Ratchasima

According to the Department of Mineral Resources and the Federal Republic of Germany (2004), hydrogeology characteristics of Nakhon Ratchasima Province are mostly underlain by consolidated rocks, composed of sandstone, shale, and siltstone of Mesozoic age. Unconsolidated rocks are found only along the Mun and Lam Takhong Rivers. The aquifer can be divided into two types, i.e. unconsolidated aquifer and consolidated aquifers. Their brief descriptions are as follows:

(1) Unconsolidated aquifer is found in two deposits: Alluvial deposits and High Terrace and Colluvium deposits.

- Alluvial deposits: aquifers in these deposits occur along the Mun and Lam Takhong Rivers. The aquifer is formed as a narrow and elongate strip following east-west directions. Groundwater is stored in sand and gravel layers at a depth between 10 and 30 meters. The layers were built up by meandering streams. They mainly consist of sand and gravel which is interbedded with thin layers of clay. However, groundwater in this layer hydraulically interconnected.

- High Terrace and Colluvial deposits: These deposits form aquifer in the hilly area south of Nakhon Ratchasima province and in the flood plain area where they are overlain by alluvial deposits. Groundwater is commonly found in sand and gravel at two distinct depth intervals: 20-40 meters and 50-70 meters below ground surface. The two sand and gravel layers are separated by a layer of fine-grained material with a thickness of about 10 meters.

(2) Consolidated aquifer is recognized in eight formations.

- Nam Phong Formation: This formation consists a sequence of siltstone, sandstone, and conglomerates. The total thickness of the formation is 1,456 meters. The aquifer rests on the Pre- Khorat erosional.

- Phu Kradung Formation: This unit has an average thickness about 972 meters. Their outcrop and sub outcrop were found around the Khorat Plateau. It is composed of shale, siltstone, sandstone, and conglomerate. Groundwater yield ranges of 10-40 cubic meter per hour are better than yield in Phu Phan and Phra Wihan Formations. Groundwater quality in term of total dissolved solids (TDS) is generally less than 50 milligram per liter.

- Phra Wihan Formation: Its thickness varies from 50 to 297 meters. This formation consists of a massive highly resistant white to pink, thick bedded, well-sorted quartz sandstone, with thin beds of laminated red siltstone. Groundwater showed good quality.

- Sao Khua Formation: This unit is composed of sandstone and siltstone, varying in thickness from 400-720 meters. It was found in areas of flat to undulating topography. Groundwater yield from many boreholes in Sao Khua aquifer ranges from 5-10 cubic meter per hour with exceptionally good quality water.

- Phu Phan Formation: The unit is characterized by massive coarse grained quartzitic sandstone with some conglomerate. Its thickness varies from 100-400 meters. Geomorphological form varies from nearly flat top hills to undulating terrain. Groundwater yield ranges from 1 to 10 cubic meter per hour. This yield amount can be expected from drilling well penetrated to fractured zones of the aquifer. Groundwater is generally good quality, with occasionally high iron contents. Flowing artesian was not found in aquifer of Phu Phan formation. Aalthough, several flowing wells have been drilled.

- Khok Kruat Formation: Groundwater mainly occurs in spaces of fractures and bedding planes of sandstone, shale, and siltstone. Groundwater quality in this formation is generally good. However, saltwater can be found in the areas where the rock is in contact with the Maha Sarakham Formation.

- Maha Sarakham Formation: Its most shallow occurrence is found at depth of around 80 to 100 meters below ground surface. From the seismic section profile, the upper surface of the rock salt is generally smooth and gently inclined to the North-East. Principally, the formation acts as an aquitard due to the non-existing primary porosity. Groundwater can only be trapped in the formation where it may be in contact with overlying porous rock units. Most salt mines pump brine water from such aquifers.

- Phu Tok Formation: It is not well cemented and slightly soft when compared to the underlying formations. It mainly comprises of claystone, siltstone, and sandstone. Where it outcrops out, this formation usually forms a flat and slightly undulating topography. The formation is competent and usually forms a good aquifer. Groundwater can be trapped in both primary and secondary porosity. The formation is underlain by rock salt layers, which may result in groundwater salinization. Groundwater in this formation is poor, due to high sodium chloride content. In some areas, local people pump salty water to produce table salt. Groundwater of low salinity can be found in areas where rock salt layers are situated at a greater depth or where freshwater forms a shallow lens above the saltwater in the recharge mounds.

Wongsawat et al. (1992) reported that groundwater quality depends on the rock type of aquifers. The shallow rock salt strata or dome (depth less than 50 meters) causes salinity in groundwater. Maha Sarakham Aquifer is characterized by evaporite or rock salt beds. This causes of groundwater quality to be ranged from brackish to saline groundwater.

2.3.2 Contamination of groundwater

Groundwater can be polluted by landfills, septic tanks, leaky underground gas tanks, and from overuse of fertilizers and pesticides. If groundwater becomes polluted, it will no longer be safe to use. When rain water infiltrates through the ground, it dissolves minerals from top soil and rocks. The dissolved materials were then drawn down to groundwater level. Rain water that runs along surface as flash flood can also dissolves minerals from top soil and rock outcrops. The dissolved materials were subsequently transported along streams which finally ended in reservoirs or lakes. The most common substances dissolved in groundwater and surface water are salts of metal sodium, potassium, calcium, magnesium, and iron. Amount of dissolution of minerals in groundwater depends on types of rocks, length of time that the water is in contact with them, and temperature of the water.

Contamination of surface water is more concerned than groundwater. When water seeps passing layers of soil and rocks, it is then naturally filtered. Pumping groundwater from depth yields considerably pure water for household consumption. Comparing with surface water which is exposed to all contaminants along the way to its end. Main water quality issues for surface water tend to be color and turbidity. Groundwater can be one of dominant sources of surface water contamination, where it reaches surface from depth at seepage areas, bringing soluble salts along with it. Groundwater contamination always occurs in areas where groundwater level is shallow. Poor chemical quality of groundwater leads to an exceedance of the quality standards in receiving surface water.

Salinity is the quantity of dissolved salt content of the water. Salts are compounds like sodium chloride, magnesium sulfate, potassium nitrate, and sodium bicarbonate which dissolve into anions and cations.

Iron is one of the most abundant metals in the Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 milligram per liter (WHO, 2008). When total dissolved solids (TDS) content water is high, this characteristic is often associated with high iron concentrations. Although iron is not harmful, it causes a lot of problems in using groundwater, it leads to undesirable bad test, smell and color.

Sodium chloride is closely related to human lives. It naturally occurs as rock salt beds and in sea water. Saline groundwater occurs where rock salt-water interacts with groundwater. When conditions are suitable, saline groundwater can seeps out at seepage and precipitates sodium chloride crystal which has become household use for centuries. However, chloride concentrations in excess of about 250 milligrams per liter can give rise to detectable taste in water (WHO, 2008).

Chemical quality of water may limit its use for domestic or municipal supply, as outlined in Table 2.1 (The Government Gazette. Rule No. 125 Section No. 85, 2008).

The total dissolved solids (TDS) in water samples is obtained by evaporating all water from samples, then the dissolved minerals residue is weighed. A unit of residue weight per sample volume is reported. The total dissolved solids (TDS) value is frequently used to assess the basic quality of groundwater and surface water. The water type can be classified, using total dissolved solid (TDS) content as showed in Table 2.2.

Risk of contamination is greater in unconfined aquifers than confined aquifers because they usually are nearer to the land surface and lack of overlying confining layer to impede the infilling of contaminants.

2.3.3 Groundwater quality of Nakhon Ratchasima

According to Department of Mineral Resources and Federal Republic of Germany (2004) and Department of Groundwater Resource (2007), total dissolved solids (TDS) content is high in northern part Nakhon Ratchasima Province. High total dissolved solids (TDS) are located in low topographic areas. The main components are sodium (Na) and Chloride (Cl) originating from rock salt dissolution. Groundwater in

Maha Sarakham Formation is usually brackish to saline. Groundwater of this high TDS content is considered to be not suitable for drinking.

Table 2.1 Standards for the composition of groundwater (The Government Gazette. Rule No. 125 Section No. 85, 2008).

Properties	Index	Unit	Maximum Acceptable Concentration	Maximum Allowable Concentration
Physical	Color	Platinum-Cobalt	5	15
	Turbidity	Silica scale unit	5	20
	pH	-	7.0 - 8.5	6.5 - 9.2
Chemical	Iron	milligram per liter	Less 0.5	1.0
	Manganese	milligram per liter	Less 0.3	0.5
	copper	milligram per liter	Less 0.1	1.5
	Zinc	milligram per liter	Less 5.0	15
	Sulfate	milligram per liter	Less 200	250
	Chloride	milligram per liter	Less 250	600
	Fluoride	milligram per liter	Less 0.7	1.0
	Nitrates	milligram per liter	Less 45	45
	total hardness as $CaCO_3$	milligram per liter	Less 300	500
	Non-carbonate hardness as $CaCO_3$	milligram per liter	Less 200	250
	Total dissolved solids	milligram per liter	Less 600	1,200

Remark: The blue highlights are index, measured in this investigation.

Table 2.2 Water type classification (Freeze and Cheery, 1979).

Water type	Total Dissolved Solid contents (TDS, milligram per liter)
Freshwater	0 to 1,000
Brackish water	1,000 to 10,000
Saline water	10,000 to 100,000
Brine water	> 100,000

Wannakomol (2012) made the groundwater map of Nakhon Ratchasima province, based on electrical survey data. Groundwater area has an electrical resistance of less than 10 ohms-meter. The shallow saline groundwater level has been found in Sikhio, Dan Khun Thot, Phra Thong Kham, Kham Sakae Saeng, Non Sung, Phimai, Kham Thale So, Mueang Nakhon Ratchasima and Chaloem Phra Kiat Districts. Maha Sarakham Formation was described as the source of groundwater salinization.

Groundwater quality and geology of study area were described as follow (DGR, 2007).

- Non Thai District: Rocks consist of shale, sandstone, siltstone, claystone and rock salt member of Maha Sarakham Formation. Rock salt is the main cause of saline and brackish groundwater. Groundwater aquifers were found in rock fractures. Groundwater yield is 2–10 cubic meter per hour. The average depth of aquifers is 15–30 meters and the water level are 3–8 meters Groundwater quality is high saline, brackish and hard.
- Non Sung District: Most of the rocks in this district are Rock salt of Maha Sarakham Formation. Therefore, the groundwater quality of Non Sung District is saline, hard, with high iron content.
- Non Daeng District: Shale, sandstone, siltstone, claystone and rock salt member of Maha Sarakham Formation are members of rocks in this district. Groundwater on river plain along Sakae River is saline and brackish, whereas on the hill groundwater is fresh. The quantity yield of groundwater is 2–10 cubic meter per hour, the average depth of aquifer is 10–30 meters and the water level are 3–8 meters.
- Khong District: Rocks consist of shale, sandstone, siltstone, claystone and rock salt member of Maha Sarakham Formation. Saline and brackish groundwater

were found in most parts of the district, however freshwater was found in some areas. The quantity of groundwater yield is 2–10 cubic meter per hour, the average depth of aquifer is 20–50 meters and the water level are 3–8 meters. Groundwater quality is saline, brackish and high hardness, whereas some of the areas are good quality.

- Kham Sakae Saeng District: Rocks consist of shale, sandstone, siltstone, claystone and rock salt member of Maha Sarakham Formation. Over 80 percent of groundwater quality is high saline, brackish and hard, whereas some areas are medium to good quality. The freshwater area of Kham Sakae Saeng District is in North and Northwest. The quantity of quantity of groundwater yield is 2–10 cubic meter per hour, the average depth of aquifer is 10–35 meters and the water level are 3–8 meters.

2.4 Saline Soil

Saline soil is a type of soil that contains high concentration of soluble salts which obstruct growth of plants. Soluble salts most commonly present are chlorides and sulfates of sodium, calcium, and magnesium. Nitrates of appreciable quantities may rarely be present. Sodium and chloride are by far the most dominant ions, particularly in highly saline soils. Although calcium and magnesium are usually present in sufficient quantities to meet the nutritional needs of crops (Abrol et al., 1988).

Problems of soil salinization in northeast Thailand is not new (Loffler and Kubiniok, 1988). The human activities that caused soil salinization are for example effluent released from private and municipal septic systems, and some overuses of agricultural chemicals. The natural sources include rock-water interactions, saline seeps, and minor atmospheric contributions. Especially in dry period, salt was found, exposed on the ground in several places (Davis et al., 1998).

The primary sources of salinity of the Khorat Plateau are salt originated in the ancient drainage basins or inland seas that evaporated during arid periods, leaving behind evaporite deposits. Salinity is the major soil degradation problem in Khorat Plateau. The problem is caused by groundwater dissolution of salts and accumulating them on the ground surface (Wannakomol, 2005). Soil salinity in northeast Thailand mostly caused by the sodium chloride (Yuvaniyama, 1999). Shallow groundwater table depth is another factor that can influence topsoil salinity. The quality of water can depend on seasons (Seeboonruang, 2013).

Base on Department of Mineral Resource (2015) the Khorat Plateau covers one-third of the country area. Twenty-nine percent of the Northeastern part, about 30.4 million Rais (1 Rai covers an area of 40x40 square meters), is mapped as saline soil terrains with three degrees of salinity (Figure 2.4).

(1) Strongly saline terrain covers 1.4 million Rais of the salt surface ground.

(2) Moderately saline terrain covers 5.7 million Rais of the scattered salt surface ground.

(3) Slightly saline terrain covers 23.3 million Rais of some scattered salt surfaced ground.

There are fifteen provinces affected by the salinity as follows: Udon Thani, Sakon Nakhon, Nakhon Phanom, Khon Kaen, Kalasin, Chaiyaphum, Maha Sarakham, Roi Et, Yasothon, Amnat Charoen, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket, and Ubon Ratchathani.

Nakhon Ratchasima is one of the provinces that is affected from salinity. There is total saline soil area about 3,424 square kilometers of agricultural area. However, salinity can improve soil structure, but it can also negatively affect plant growth and crop yields. The salt-affected soils in Northeastern Thailand are generally sandy, low in fertility and high in sodium and chloride content. Salt crystals combined with a high soil water content near the surface also provide additional visual indicators of saline land.

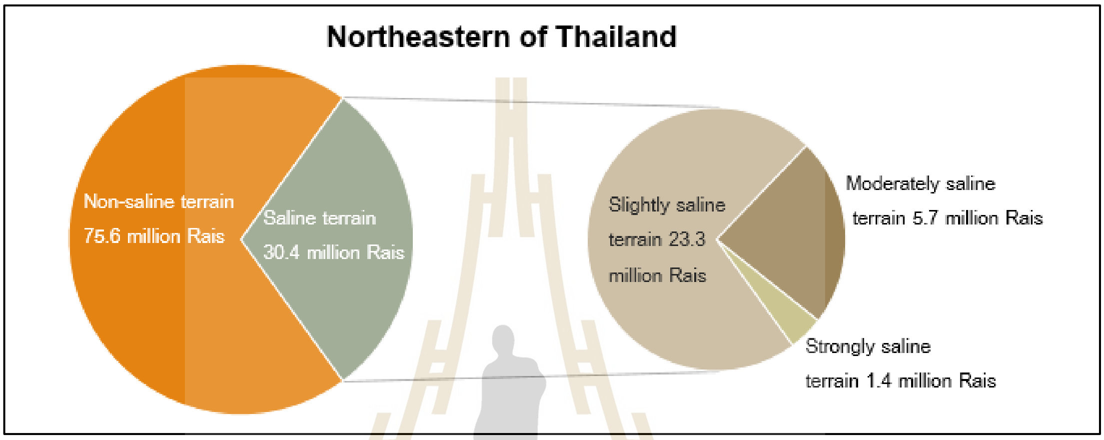


Figure 2.4 Saline affected area in Northeastern Thailand (DMR, 2015).

Major sources of salinity in the Khorat Plateau are the Rock Salt Members, which consist of up to 700 meters thick. Salts accumulated in the form of gypsum, sulfate, and carbonate in the salt-bearing layer of the Upper Clastic Member of Maha Sarakham Formation, and from some of the salty Plio-Pleistocene sediments. The saline soil is caused naturally by rock salts, which are dissolved by the groundwater and dispersed in the lowland where the groundwater table is very shallow. One serious crisis, causes by saline soil is deforestation. Table 2.3 showed the five classes of the generally recognized saline soils level and the effect on crops.

2.5 Sample analysis

Satargsa et al. (2008) analyzed electrical conductivity (EC), total dissolved solids (TDS) and chloride ion for groundwater and surface water.

Table 2.3 General ranges of soil salinity and term of saline levels (U.S. Soil Salinity Laboratory Staff, 1954).

Salinity (EC, Deci-siemens per meter)	Saline Level
0 to 2	Non-saline
2 to 4	Slightly saline
4 to 8	Moderate saline
8 to 16	High saline
> 16	Extreme saline

Seeboonruang (2011) determined the chemical properties of soil and groundwater sample, included pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity.

Singh and Agrawal (2012) used the principal component analysis (PCA) to have an idea of the minerals present, in a qualitative manner, in the soil sample. The elemental concentrations determined by the energy dispersive X-ray fluorescence (EDXRF) technique. X-ray diffraction (XRD) analysis of soil samples to identify the minerals of major elements

Ferreira et al. (2000) used flame atomic absorption spectroscopy (FAAS) to find a trace of copper in seawater sample directly.

Therefore, in this study, groundwater and surface water samples were analyzed for chemical properties, consisting of pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, chloride content, mineral composition, and elemental composition.

2.5.1 pH

The pH is a logarithmic scale, used to specify the acidity or basicity of an aqueous solution. It is approximately the negative of the base 10 logarithms of the molar concentration, measured in units of moles per liter of hydrogen ions. The solutions with a pH less than 7 are acid and more than 7 are base. Pure water is neutral, pH 7 at (25 °C), being neither acid nor base.

Measurement of soil pH has been done by putting 10g of sample into a container and adding 50ml of distilled water. Then the container was shaken for about 2-3 minutes. The solution was left to settle for 5 minutes. If the soil has a high clay content and requires a very accurate result, it is necessary to filter out the suspended materials. If filtering is not required, measuring of pH value by the pH meter can be done directly in water lying above the soil in the container. Then read the value on the digital readout.

2.5.2 Electrical conductivity (EC)

Electrical conductivity (EC) value is use to indicate classes of salinity in any water solution. It can be simply measured by using electrical conductivity meter. Probe or sensor consists of two metal electrodes. A constant voltage is applied to one of the electrodes, resulting in electrical current flowing from one electrode to another through the solution. Since the current flowing through the water solution is proportional to the concentration of dissolved ions in the water, thus the electrical current or conductivity of solution can be measured. The higher the dissolved salt concentration, the more conductive of the sample, and hence the higher the conductivity reading.

In soil, the electrical conductivity (EC) reading shows the level of ability the soil water to carry an electrical current. The electrical conductivity levels of the soil water are a good indication of a number of nutrients available for crops to absorb.

An electrical conductivity (EC) meter measures the potential for an electrical current to be transported through water known as molar conductivity (electrolytic conductivity) and expressed unit as Deci-siemens per meter (ds/m).

Measurement of the soil electrical conductivity recommends a similar method as pH measurement.

2.5.3 Total dissolved solids (TDS)

Total dissolved solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that the solids must be small enough to survive filtration through a filter with two-micrometer (nominal size, or smaller) pores. Total dissolved solids (TDS) are used as an aggregate indicator of the presence of a broad array of chemical contaminants. Measurement of the total dissolved solids (TDS) value uses the total dissolved solids (TDS) meter so that both electrical conductivity (EC) and total dissolved solids (TDS) measurements can be taken at the same time. It is usually expressed in parts per million (ppm).

2.5.4 Salinity content

Salinity is the measure of the amount of dissolved salts in water. It is usually expressed in parts per thousand (ppt). Freshwater from rivers has a salinity value of 0.5ppt or less. The salinity can be measured, using salinometer.

2.5.5 Chloride content

Analysis of chloride content is conducted by Mohr method. The Mohr Method uses silver nitrate for titration and the indicator (potassium chromate) is added to visualize the endpoint, demonstrating the presence of excess silver ions.

The Mohr method uses chromate ions as an indicator in the titration of chloride ions with a silver nitrate standard solution. After all, the chloride has been precipitated as white silver chloride, the first excess of titrant results in the formation of a silver chromate precipitate, which signals the endpoint

The reactions are:

$$Ag^{+} + Cl^{-} \leftrightarrow AgCl\,(s)$$

$$2Ag^{+} + CrO_4^{2-} \leftrightarrow Ag_2CrO_4\,(s)$$

By knowing the stoichiometry and moles consumed at the endpoint, the amount of chloride in an unknown sample can be determined.

2.5.6 X-ray diffraction (XRD)

X-ray diffractometers consist of three basic components: i.e. an X-ray tube, a sample holder, and an X-ray detector. X-ray is generated in a cathode ray tube by heating a filament to produce electrons. Subsequently, the electrons are accelerated toward target by applying high voltage, causing bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced. A detector records and processes this X-ray signal and converts the signal to a count rate which is then output to a device such as a printer or a computer monitor. X-ray diffraction is most widely used for identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies of geology, and environment including characterization of crystalline materials, identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically, and measurement of sample purity.

2.5.7 X-ray fluorescence (XRF)

An X-ray fluorescence (XRF) spectrometer is an X-ray instrument used for routine, relatively non-destructive chemical analyses of rocks, minerals, sediments, and fluids. It works on wavelength-dispersive spectroscopic principles that are similar to an electron microprobe (EPMA). However, the XRF cannot generally make analyses at the small spot sizes typical of EPMA work (2-5 microns), so it is typically used for bulk analyses of larger fractions of geological materials. The relative ease and low cost of sample preparation, and stability of analysis, making X-ray spectrometers to be the most widely used methods for the analysis of major and trace elements in rocks, minerals, and sediment.

2.5.8 Flame atomic absorption spectroscopy (FAAS)

Flame Atomic Absorption Spectrometer is a tool for analyzing various elements in water samples, based on the principle of absorption of free atoms. Independent atoms are liberated from sample solution by burning in flame while samples were sprayed into flame. When light of the same wavelength of the elemental atom passes through the flame, it will be absorbed in proportion to concentration of free atoms. Radiation sources are hollow cathode lamps (HCL). Inside the sealed lamp, filled with argon or neon gas at low pressure. Hollow cathode lamps (HCL) are the common radiation source in FAAS. The comprehensive comparison evaluation method is the most often used evaluation techniques. The comprehensive technique can be applied in case of big number of samples of the same type. The parts of the calibration series are usually diluted from a stock solution with standard concentration. This method provides analytically reliable results only in case of samples belonging to the same type with relatively stable composition. A typical calibration diagram from a comprehensive evaluation method is shown in Figure 2.5.

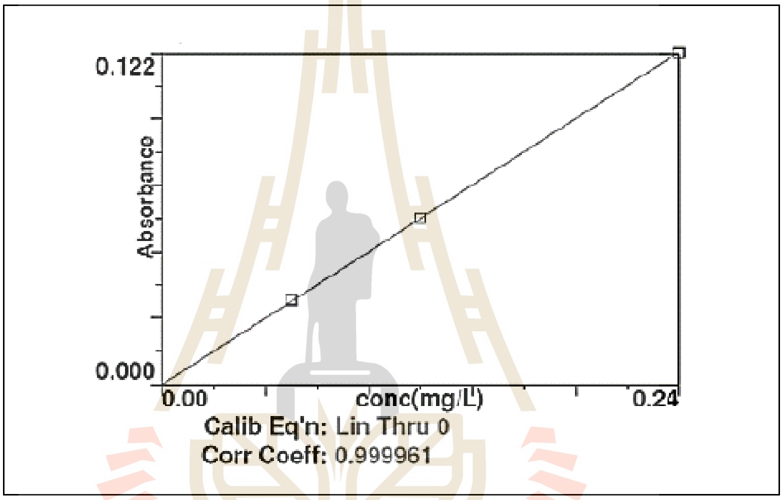


Figure 2.5 Comparison evaluation method.

CHAPTER III

SAMPLE COLLECTIONS AND ANALYSES

3.1 Introduction

The purpose of this research study is to determine relationship between soil salinity and chloride content in groundwater within saline soil areas.

A variety of data was obtained from various regional and local government offices. The data included land use maps from the Land Development Department, annual rainfall data from the Meteorological Department, the quality of surface water data from the Pollution Control Department, and borehole log and groundwater data from the Groundwater Resource Department. All of these datasets were compiled together to locate appropriate soil, groundwater, and surface water sampling locations. The soil and groundwater samples were collected during the rainy season on October 2017, and the dry season on May 2018.

3.2 Study area

Nakhon Ratchasima Province is located in northeastern Thailand, covering approximately 20,493.96 square kilometers. The provincial average climate was reported to be temperature of 27.40 °C, relative humidity of 71 percent and average annual rainfall of 1,028.10 millimeters.

The study area covers 5 districts of Nakhon Ratchasima Province, i.e. Non Thai, Non Sung, Non Daeng, Khong, and Kham Sakae Saeng (Figure 1.1). Locations of sampling sites of soil, groundwater and surface water samples were listed in Table 3.1, 3.2 and 3.3, respectively.

3.3 Sample collection

3.3.1 Collection of soil samples

Drawing of soil sample collection is depicted in Figure 3.1. A shovel was used to dig a triangular hole with sharp angle wall. Depth of hole was about 15 centimeters. Then slap of soil about 2-3 centimeters thick was cut from the wall. The samples were kept in plastic bags with prior labelling (RID,2007).

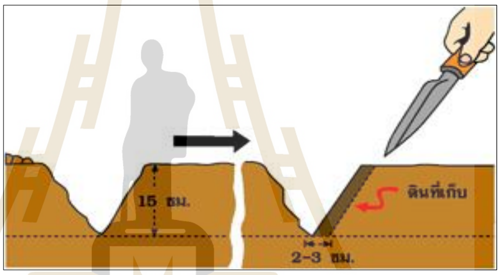


Figure 3.1 Collection of soil sample (RID,2007).

3.3.2 Collection of groundwater samples

Groundwater samples were collected from groundwater bore holes, either installed with hand pump of submersible pump (Figure 3.2). The faucet was cleaned by clean cloth before pumping out water for 5 minutes to discard unwanted deposited materials. Subsequently, groundwater samples were kept in labelled plastic bottles, which was washed by groundwater sample 1-2 times prior to sample collection.

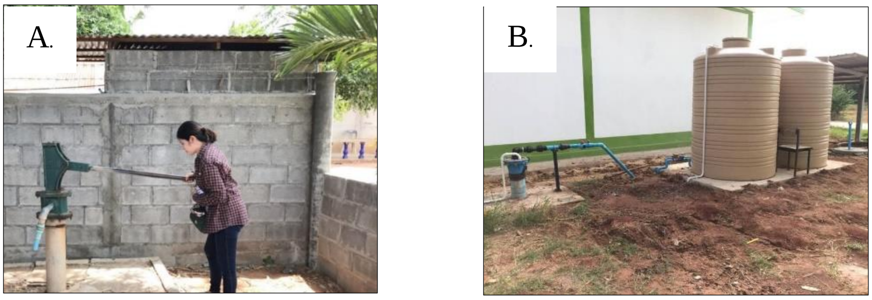
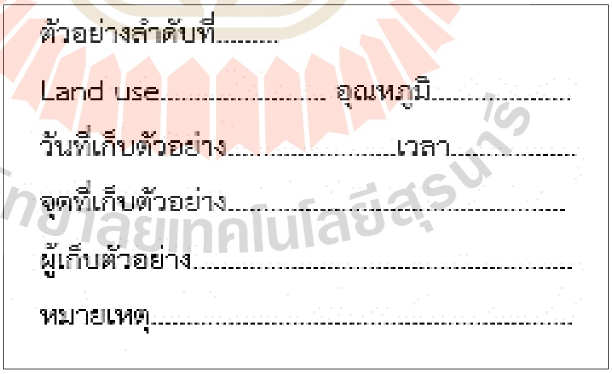


Figure 3.2 Collection of groundwater samples (**A)** groundwater hand pump, and (**B**) groundwater submersible pump.

3.3.3 Collection of surface water samples

Surface water samples were collected by wading or streamside sampling from banks of the river. Then they were kept in plastic bottles that have been washed by water sample 1-2 times. Labelling of sample containers was done with description as seen in Figure 3.3.


ตัวอย่างลำดับที่.........

Land use......................... อุณหภูมิ.....................

วันที่เก็บตัวอย่าง........................เวลา...................

จุดที่เก็บตัวอย่าง...

ผู้เก็บตัวอย่าง...

หมายเหตุ...

Figure 3.3 The label of sample.

Table 3.1 Locations of soil samples.

Site	District	Subdistrict	UTM E	UTM N	Location	Remarks
1	Non Daeng	Don Yao Yai	232976	1709975	Ban Don Yao Yai	Rice field
2		Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	-
3		Don Yao Yai	235888	1706652	Ban Ra Han Kai	-
4		Don Yao Yai	231433	1707268	Ban Pa Ta Bang	-
5		Samphaniang	240107	1711089	Ban Samphaniang Mai	-
6		Samphaniang	235598	1712364	Ban Na Khu temple	-
7		Samphaniang	235817	1711564	Ban Hua Talad	-
8		Samphaniang	237465	1711266	Ban Fang school	-
9		Wang Hin	235813	1712985	Ban Toie	Rice field
10		Wang Hin	236232	1714263	Ban Toie temple	-
11		Wang Hin	239537	1713359	Ban Hin Tang	-
12		Non Ta Then	231234	1710843	Ban Non Ta Then	-
13		Non Ta Then	232310	1711124	Ban Non Ta Then temple	-
14		Non Ta Then	228668	1709073	Ban Non Noi	-
15	Non Thai	Dan Chak	187902	1679575	Ban Dan Chak	-
16		Dan Chak	188274	1678720	Ban Dan Chak temple	-
17		Non Thai	184673	1682935	Sai Mit Non Thai school	-
18		Sam Rong	178417	1673084	Ban Song Tham	-
19		Sam Rong	178814	1671006	Ban Nong Krad	-
20	Non Sung	Mai	209858	1675501	Ban Jan Dum 1	-
21		Mai	210482	1679135	Ban Jan Dum 2	Sugarcane farm
22		Lum Khao	210114	1680537	Ban Chad	-
23		Bing	210826	1674312	Ban Bing	-
24		Bing	213043	1674234	Ban Pet	-
25		Than Prasat	218707	1677319	Ban Mai Kasem	-
26		Don Chomphu	214228	1680448	Ban Som	Rice field
27		Don Chomphu	214406	1677123	Ban Don Chomphu	Rice field
28		Don Chomphu	214590	1678757	Ban Plo Pla	-
29	Khong	Thephalai	228122	1702977	Thephalai school	-
30		Thephalai	226707	1699278	Ban Wat	-
31		Kham Sombun	222077	1700185	Ban Kham school	-
32		Ta Chan	220572	1694233	Ban Ta Chan	-
33		Khu Khat	222455	1706779	Wat Koo Sa Mak Kee school	-
34		Khu Khat	225005	1708358	Ban Ngiow	-
35		Khu Khat	219948	1706120	Ban Pho Bit	-
36		Mueang Khong	212267	1703423	Ban Don Yai	-
37		Mueang Khong	211910	1708271	Ban Nong Khaem	-
38		Mueang Khong	211224	1708348	Ban Non Wat	-
39		Ban Prang	187597	1715276	Wat Pa Prang Thong	-
40		Nong Bua	192530	1717177	Ban Ta Kim	-
41	Kham Sakae Saeng	Mueang Kaset	196954	1703106	Ban Rim Bung	-
42		Nong Hua Fan	202892	1705899	Ban Nong Hua Fan 1	-
43		Nong Hua Fan	202822	1706078	Ban Nong Hua Fan 2	-
44		Nong Hua Fan	200940	1709601	Ban Non Ban Na	-
45		Chiwuek	191176	1698356	Chiwuek temple	-
46		Kham Sakaesaeng	197182	1703411	Ban Nong Jan school	-
47		Kham Sakaesaeng	195905	1700730	Ban Non Jang	-
48		Mueang Nat	206618	1702113	Ban Sema	-
49		Mueang Nat	203192	1704728	Mueang Nat temple	-
50		Mueang Nat	206028	1702416	Ban Mueang Nat	-

Table 3.2 Locations of groundwater samples.

Well no	District	Subdistrict	UTM E	UTM N	Well no.	Location	Remarks
1	Non Daeng	Non Daeng	238141	1706668	5705D031	Non Daeng Municipal school	-
2		Non Daeng	238343	1705364	5405B007	Phu Wittaya school	-
3		Samphaniang	238705	1711383	NR270	Ban Nong Ya Khao	-
4	Non Thai	Banlang	170377	1689973	MG799	Ban Muang Kao school	-
5		Banlang	170363	1690249	-	Ban Muang Kao 1	Private well
6		Banlang	170357	1688964	-	Ban Muang Kao 2	Private well
7		Banlang	170013	1689327	-	Ban Muang Kao 3	Private well
8		Banlang	170683	1689675	SC409	Ban Muang Kao temple	-
9		Sai O	181412	1691223	-	Ban Sawai	Private well
10		Thanon Pho	192879	1693814	PW13862	Ban Nong Ta Maen	-
11		Makha	187792	1689952	MG1571	Nong Doom health promoting hospital	-
12	Non Sung	Lum Khao	215050	1687249	-	Ban Dong Plong	Private well
13		Lum Khao	209452	1684940	-	Ban Krok Kham	Private well
14		Than Prasat	222250	1687690	-	Ban Talad Kae	Private well
15		Dan Khla	203592	1674430	-	Ban Bu	Private well
16		Tanot	206821	1671468	D0516	Ban Non Makok	-
17		Phon Sungkhram	212794	1698603	-	Ban Salao	Private well
18	Khong	Non Teng	206847	1708043	MY610	Ban Non Thong	-
18		Non Teng	206466	1707680	MY853	Ban Non Thong temple	-
20		Non Teng	207618	1709139	PW16	Ban Nong Bua Gra Jai school	-
21		Nong Manao	207201	1716400	5805D004	Ban Don Klang school	-
22		Nong Manao	206169	1716165	5805A004	Ban Taluk Nam Khwang	-
23		Nong Bua	195999	1717793	MG679	Ban Nong Sakae school	-
24		Nong Bua	197134	1717526	AFD815	Ban Tha Yai 1	-
25		Nong Bua	197358	1717630	MY619	Ban Tha Yai 2	-
26		Nong Bua	192508	1717165	5505G052	Ban Ta Kim	Bad odor
27		Nong Bua	197316	1714455	25111	Ban Ba Dao Rueang	-
28		Mueang Khong	214581	1714842	5405B019	Ban Don Du	-
29		Mueang Khong	214630	1710905	MG1014	Ban Kok Pet 1	-
30		Mueang Khong	214775	1711005	MG832	Ban Kok Pet 2	-
31		Mueang Khong	215532	1711669	MY327	Ban Kok Pet temple	-
32		Ban Prang	184962	1715211	PW20092	Ban Mai Don Tua Pap	-
33		Ban Prang	185261	1715430	MG1017	Ban Don Tua	-
34		Ban Prang	184921	1712189	AFD806	Ban Huay Luek	-
35		Ban Prang	184934	1710462	5905H052	Ban Thap Ma Kham school	-
36	Kham Sakae Saeng	Non Mueang	191889	1706585	5805B035	Ban Non Mueang school	-
37		Non Mueang	188468	1705543	SC1145	Ban Taluk Hin	-
38		Non Mueang	191207	1708251	MY331	Ban Ngio school	-
39		Non Mueang	189356	1706970	MY337	Ban Khum Muang	-
40		Non Mueang	191778	1706565	MG320	Ban Sa Kruat	-
41		Mueang Kaset	195665	1706447	5605B031	Ban Khu Mueang school	-
42		Nong Hua Fan	201683	1706461	5905D059	Chomcho Nong Hua Fan school	-
43		Nong Hua Fan	198289	1710131	MY228	Ban Non Makluea temple	-
44		Nong Hua Fan	198165	1710145	5505C054	Ban Non Makluea school	-
45		Nong Hua Fan	207082	1705864	MG1637	Ban Jod school	-
46		Chiwuek	188847	1695635	5905H029	Chiwuek 1	-
47		Chiwuek	187952	1700628	5805H044	Chiwuek 2	-
48		Chiwuek	188906	1696058	PW73	Ban Hua Bung	-
49		Chiwuek	187583	1697185	MY458	Ban Nong Pho	-
50		Chiwuek	186671	1698911	5805H049	Ban Non Phak Chi school	-
51		Kham Sakaesaeng	201285	1698994	MG1441	Ban Nook 1	-
52		Kham Sakaesaeng	201393	1698950	MG1442	Ban Nook 2	-
53		Kham Sakaesaeng	200904	1699036	MG1443	Ban Nook school	-
54		Kham Sakaesaeng	203193	1699010	MG318	Ban Namab	-
55		Kham Sakaesaeng	196920	1694693	AFD998	Ban Bu La Kro	-
56		Mueang Nat	208529	1701210	5705B005	Ban Sema school	-
57		Mueang Nat	204767	1699728	AA1655	Ban Nong Pho Namab school	-

Table 3.3 Locations of surface water samples.

Site no	District	Subdistrict	UTM E	UTM N	Location	Remarks
1	Non Daeng	Non Daeng	231234	1710843	Non Ta Then reservoir	-
2		Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	-
3		Samphaniang	237465	1711266	Huai Fang	-
4	Non Thai	Dan Chak	188274	1678720	Ban Dan Chak reservoir	-
5		Non Thai	183315	1680970	Don Bot temple reservoir	-
6	Non Sung	Bing	210826	1674312	Ban Bing reservoir	-
7		Than Prasat	219142	1688112	Lum Than Prasat river	Ban Mai Kasem Tai
8		Don Chomphu	215493	1682185	Lum Chiang Krai river	Ban Som
9	Khong	Khu Khat	222394	1706686	Kud Vien reservoir	-
10		Mueang Khong	211620	1702627	Bueng Don Yai reservoir	-
11		Kham Sombun	221489	1700984	Non Si Fun reservoir	-
12	Kham Sakae Saeng	Kham Sakaesaeng	196920	1694693	Ban Bu La Kro reservoir	-
13		Kham Sakaesaeng	195785	1701679	Ban Yakha Non Jang school reservoir	-
14		Kham Sakaesaeng	197128	1703284	Non Lan canal	-

3.4 Sample preparation

3.4.1 Preparation of soil samples

Soil samples were split into two portions. The first portion was dried and crushed to be powder. The sample powder was then sieved through 1 mm screen. The second portion was dissolved by water. The solution then was filtered by Filter press machine with filter paper No 50. Powder samples were used in analysis by X-ray diffraction (XRD) and X-ray fluorescence spectrometer (XRF). The filtered solution portion was used in measuring for various chemical properties. Figure 3.4 demonstrates preparation tools for soil and water samples.

3.4.2 Preparation of water samples

Debris in groundwater and surface water samples was removed by filtering through filter paper No 50. Then water samples were stored in ventilated area before analysis.

3.5 Sample analysis

Determination of soil, groundwater, and surface water properties, included pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity content was done by using portable meters (Figure 3.5) on the sampling sites. Chloride contents were analyzed by titrations in laboratory.

Analysis of the mineral composition soil samples was done by X-ray diffractometer (XRD). X-ray fluorescence analysis was used to determine percent by weight of metal oxides in soil samples. Flame atomic absorption spectroscopy (FAAS) was employed to determine atomic elemental composition of soil samples and some selective groundwater, and surface water samples.

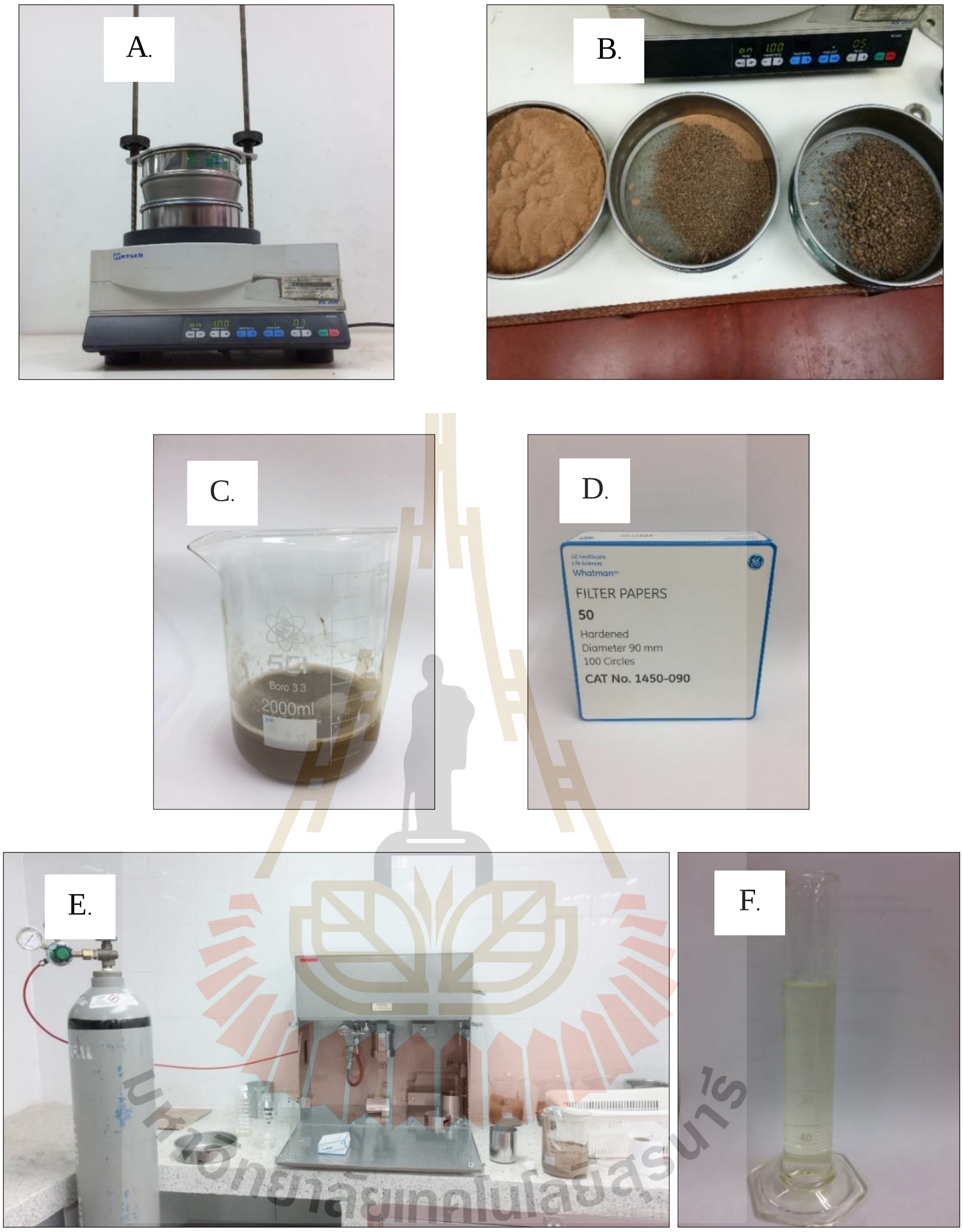


Figure 3.4 Preparation tools for soil samples; **(A)** sieving machine, (**B)** pan, 1 mm sieve, and 2 mm sieve, respectively from left to right, **(C)** soil solution, **(D)** filter paper no 50, **(E)** filter press machine, and **(F)** filtered water.

Figure 3.5 The pH, electrical conductivity (EC) and total dissolved solids (TDS), and salinity content meters respectively from left to right.

3.5.1 Chloride content

Chloride contents were analyzed by Mohr's method. In this analytical method, silver nitrate was used in titration stage, while potassium chromate was added as indicator to visualize the endpoint, demonstrating the presence of excess silver ions.

The solution includes a potassium chromate, standardization of sodium chloride, and standardization of 0.01 M silver nitrate. The stages of titration for chloride content are as follows (Figure 3.6).

1. Put 10 milliliters of water sample in a 250 milliliters flask, then added 40 milliliters of distilled water.
2. Add 1 milliliter of potassium chromate as indicator. Color of the sample turned to be yellow.
3. Add 0.01 M silver nitrate solution, to obtain white precipitate of silver chloride. Color of sample solution changed from yellow to reddish brown. This is the endpoint. Finally, quantity of silver nitrate was used for calculation of chloride

contents. The experiment was repeated 3 times. Average value of chloride was reported in Chapter IV.

Figure 3.6 Chloride content analysis **(A)** Standard solution 0.01 M silver nitrate, potassium chromate, and sodium chloride, **(B)** add indicator to the sample, **(C)** titration of chloride content, and **(D)** color of the sample at the endpoint.

3.5.2 X-ray diffraction (XRD)

X-ray diffraction (XRD) is a rapid analytical technique, primarily used for phase identification of a crystalline material, and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined.

All diffraction methods are based on the generation of X-rays in an X-ray tube. These X-rays are directed at the sample, and the diffracted rays are collected. A key component of all diffraction is the angle between the incident and diffracted rays. Powder and single crystal diffraction vary in instrumentation beyond this. Figure 3.7 (A and B) showed the characteristic of sample preparation tools for X-ray diffraction, and the X-ray diffraction instrument, respectively.

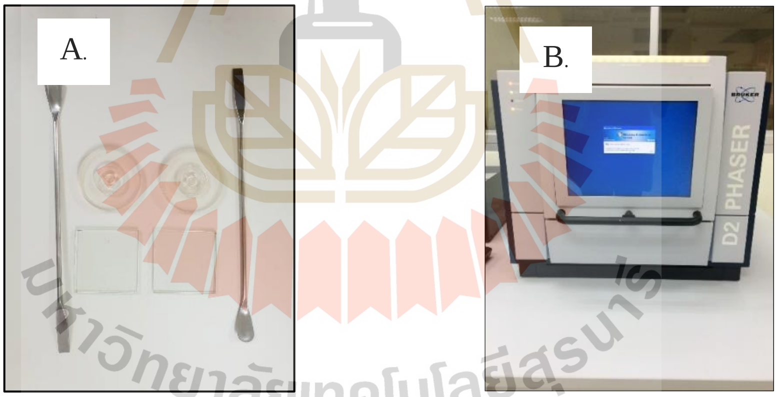


Figure 3.7 X-ray diffraction analysis; **(A)** Equipments for preparation of sample, and (**B)** XRD-D2 machine.

3.5.3 X-ray fluorescence spectrometer (XRF)

The analysis of major and trace elements in geological materials by X-ray fluorescence spectrometer is made possible by the behavior of atoms when they interact with radiation. When materials are excited with high-energy, short wavelength radiation (X-rays), they can become ionized. If the energy of the radiation is sufficient to dislodge a tightly-held inner electron, the atom becomes unstable and an outer electron replaces the missing inner electron. When this happens, energy is released due to the decreased binding energy of the inner electron orbital compared with an outer one. The emitted radiation is of lower energy than the primary incident X-rays and is termed fluorescent radiation. Because the energy of the emitted photon is characteristic of a transition between specific electron orbitals in a particular element, the resulting fluorescent X-rays can be used to detect the abundances of elements that are present in the sample. Figure 3.8 showed tools for sample preparation and X-ray fluorescence spectrometer machine.

Figure 3.8 X-ray fluorescence spectrometer; **(A)** sample preparation tools, and **(B)** WD-XRF machine.

3.5.4 Flame atomic absorption spectroscopy (FAAS)

In this study, analyses for sodium, magnesium, potassium, calcium, and iron contents were undertaken by Flame Atomic Absorption Spectroscopy (FAAS). Process of analyses was conducted as in following steps.

1. Prepare standard solution of particular elements to be analyzed at different concentrations (Figure 3.9).
2. Install the hollow cathode lamps (HCL) into the machine (Figure 3.10). Then the computer program will adjust the wavelength to suit the analysis of the element.
3. Feed standard solution of different concentration to make calibration curve.
4. Feed prepared water samples to the machine. First, the machine will read absorbance of the sample then later calculates the concentration of the element (milligram per litter) in the sample. Repetition of analysis was made 3 times.

Figure 3.9 Standard chemicals for Flame Atomic Absorption Spectroscopy (AAS) analysis.

Figure 3.10 Hollow cathode lamp.

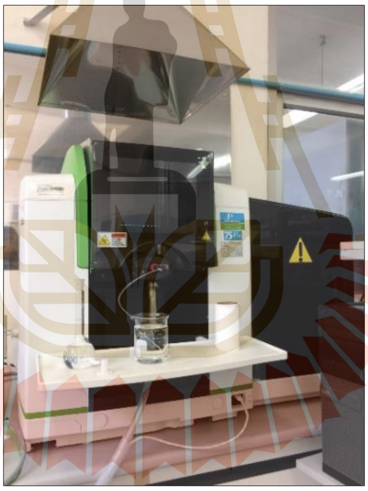


Figure 3.11 Flame Atomic Absorption Spectroscopy (FAAS) machine.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

This chapter exhibits the results of laboratory experiments and discussion of the results. Comparisons of analytical results related to different seasons were also done.

4.2 Field measurments

4.2.1 pH

Analytical pH values of soil, groundwater and surface water from the same sampling site were averaged to represent pH value of that particular site. Further, averaged pH values from various sampling sites within a subdistrict were averaged again to represent that particular subdistrict. The pH values were statistically illustrated as bar charges as seen in Figures 4.1 to 4.5. Each figure visaullises pH values in a district within study area. Two bars of diffent seasons from the same sampling site were drawn adjacent to each other for comparison.

- The pH values of samples from Non Thai district are almost neutral in both seasons, except the weak basic value of 9.19, appearing in dry season samples from Samrong subdistrict (Figure 4.1).

- The pH values of samples from Non Sung district are almost neutral in both seasons, except the weak basic value of 9.00, appearing in dry season samples from Mai subdistrict (Figure 4.2).
- The pH values of samples from Non Daeng district are almost neutral in both seasons, except the weak basic values of 9.13 and 9.08, appearing in dry season samples from Wang Hin and Non Ta Then subdistrict, respectively (Figure 4.3).
- The pH values of samples from Khong district are almost neutral in both seasons, but more weak basic values of 8.91, 9.36, and 8.52 appearing in dry season samples from Thepalai, Ta Chan, and Ban Prang subdistrict, respectively (Figure 4.4).
- The pH values of samples from Kham Sakae Saeng district tend to be different fron the other four districts. The areas in this district are more acidic. All samples of dry season are neutral. Almost all rainy season samples are weakly acidic, except samples with neutral values of 6.77, 6.88, and 6.80 were found in Mueang Kaset, Kham Sakae Saeng and Non Mueang subdistrict, respectively (Figure 4.5).

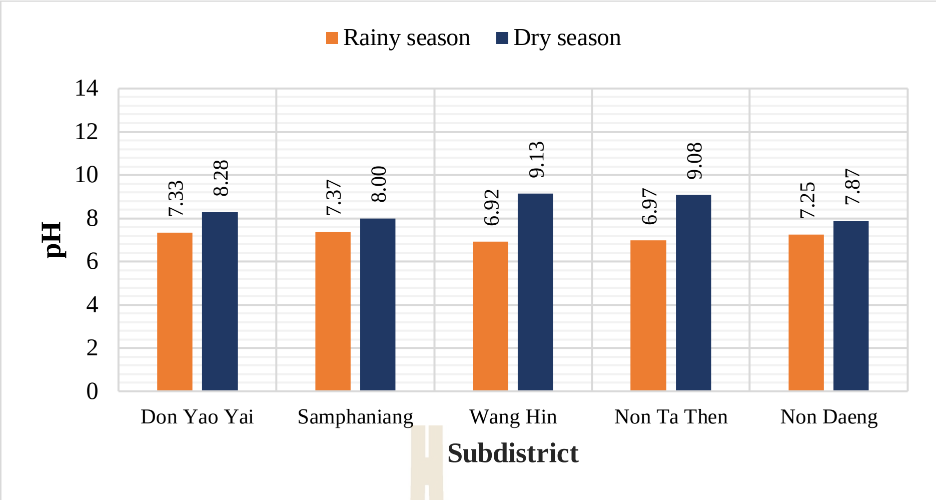


Figure 4.1 The pH of Non Daeng district.

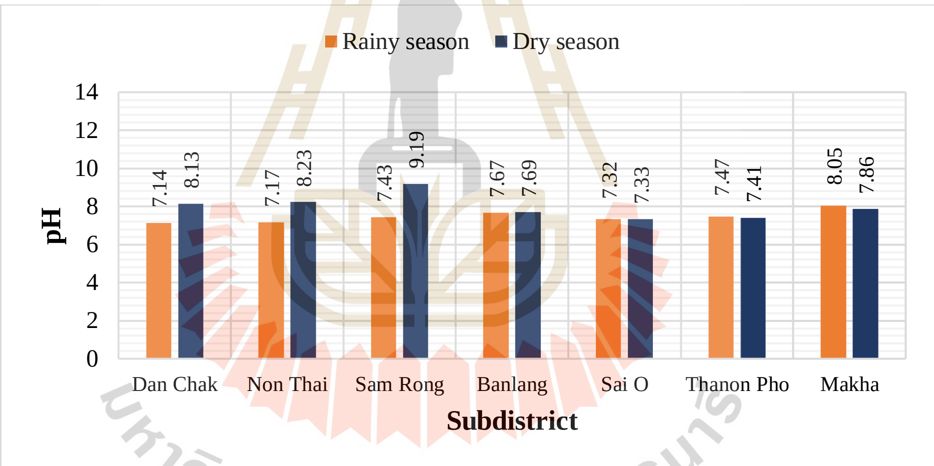


Figure 4.2 The pH of Non Thai district.

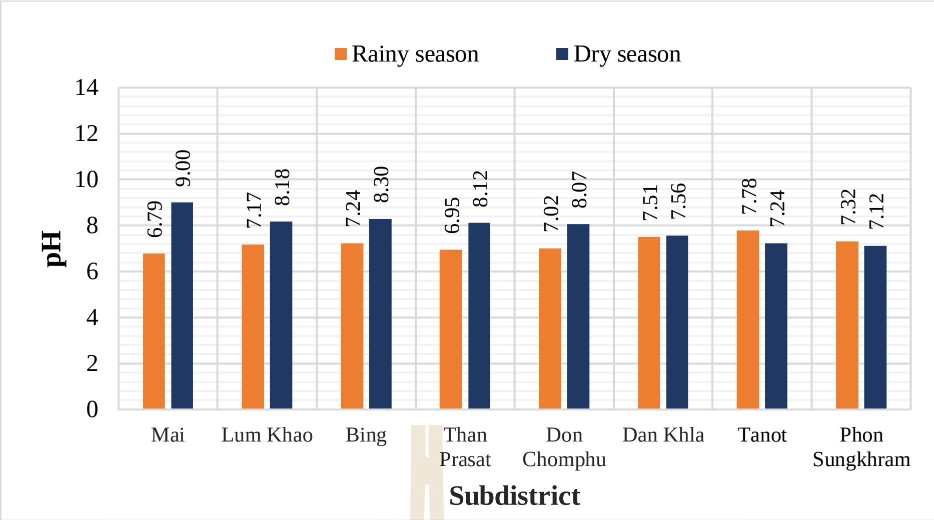


Figure 4.3 The pH of Non Sung district.

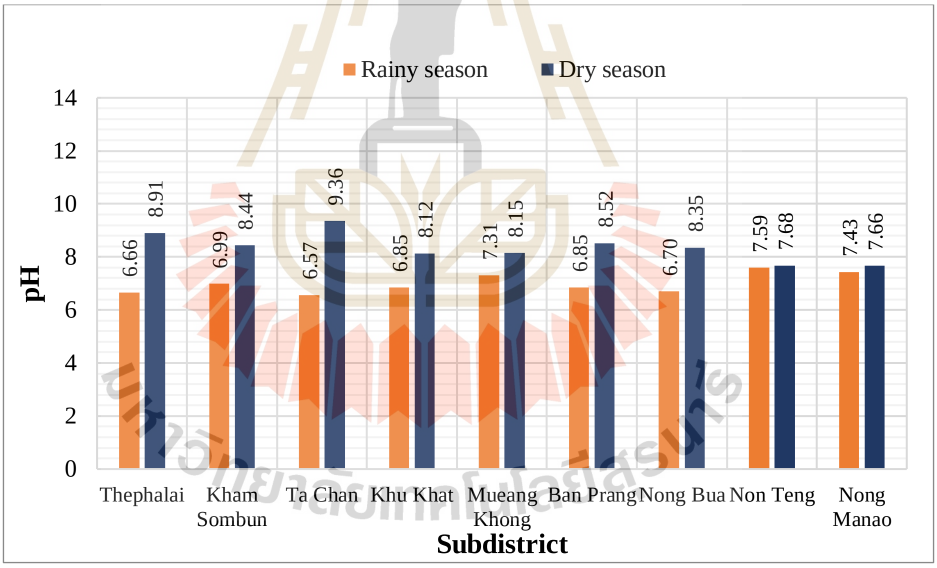


Figure 4.4 The pH of Khong district.

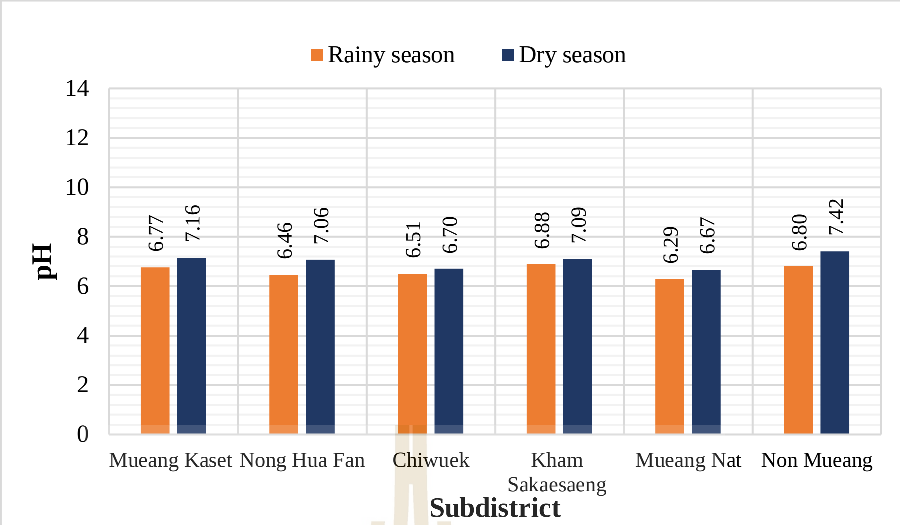


Figure 4.5 The pH of Kham Sakae Saeng district.

4.2.2 Electrical conductivity (EC) and Total dissolved solids (TDS)

In this study, salinity in soil, groundwater and surface water samples are present in form of its electrical conductivity value. Total dissolved solid value of the same sample was plotted coincidentally against sampling location numbers in the same graph as of electrical conductivity. Notably, sampling location numbers were displayed as seen in Tables 3.1-3.3.

Salinity content can be categorized as;

- Non-saline = EC between 0 and 2,000 us/cm
- Slight saline = EC between 2,000 and 4,000 us/cm
- Moderate saline = EC between 4,000 and 8,000 us/cm
- High saline = EC between 8,000 and 16,000 us/cm
- Extreme high saline = EC more than 16,000 us/cm

A simple scheme for groundwater categorization based on total dissolved solid is as; (Freeze and Cherry, 1979).

- Fresh water = TDS between 0 and 1,000 ppm
- Brackish water = TDS between 1,000 and 10,000 ppm
- Saline water = TDS more than 10,000 ppm

Results of analyses for electical conductivity and total dissolved solid will be discussed in relation to types of sample as follow:

- Analytical results of soil samples

It is clearly seen that electrical conductivity (EC) and total dissolved solid (TDS) values of the same season at each sampling site relatively varies conformably with each other in all districts (Figures 4.6-4.10). On the other hand, EC values vary from non-saline to extremely high saline (0 to more than 16,000 us/cm) in both rainy and dry season. TDS values vary from 0 to more than 15,000 ppm in both rainy season and dry season.

In conclusion, EC and TDS values of dry season are higher than values of rainy season, except some irregularity in some locations.

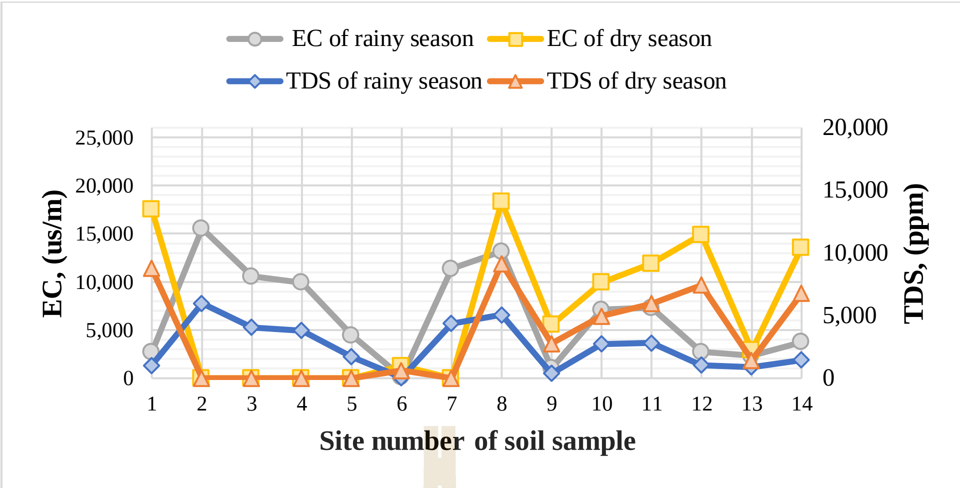


Figure 4.6 The electrical conductivity (EC) and total dissolved solids (TDS) of soil samples at Non Daeng district.

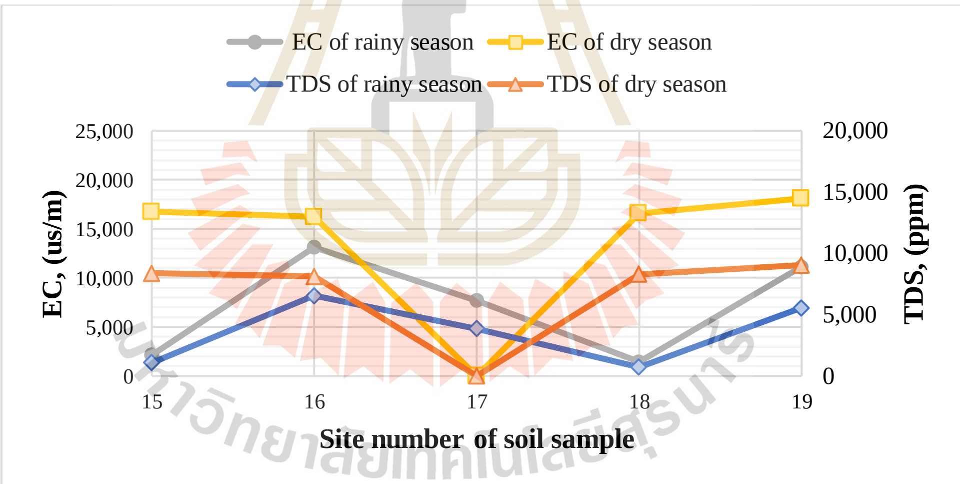


Figure 4.7 The electrical conductivity (EC) and total dissolved solids (TDS) of soil samples at Non Thai district.

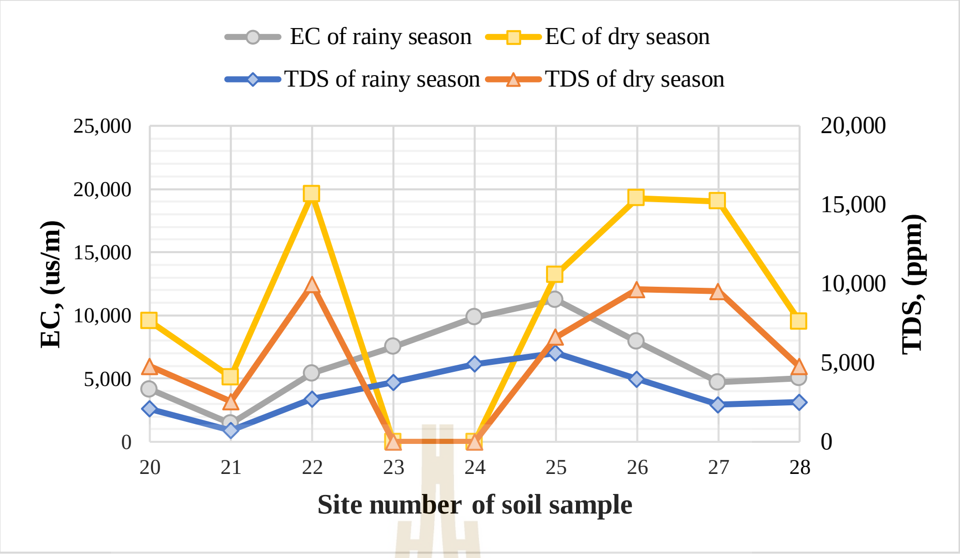


Figure 4.8 The electrical conductivity (EC) and total dissolved solids (TDS) of soil samples at Non Sung district.

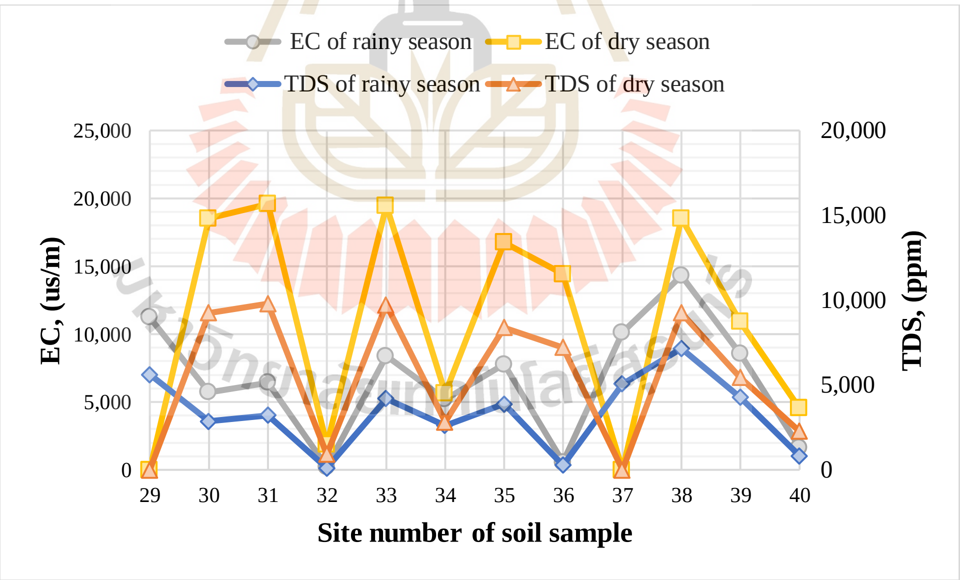


Figure 4.9 The electrical conductivity (EC) and total dissolved solids (TDS) of soil samples at Khong district.

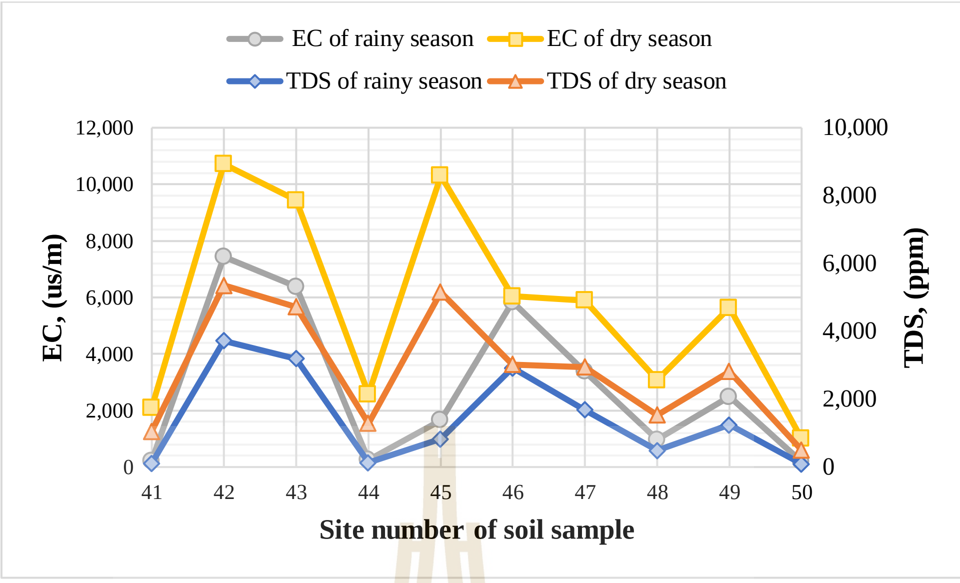


Figure 4.10 The electrical conductivity (EC) and total dissolved solids (TDS) of soil samples at Kham Sakae Saeng district.

- Analytical results of groundwater samples

It is evident that electrical conductivity (EC) and total dissolved solid (TDS) values of the same season at each sampling site relatively varies conformably with each other in all districts (Figures 4.11-4.15). Moreover, EC and TDS values of dry season are comparatively higher than of rainy season.

Considering salinity in groundwater samples of both rainy and dry season, most of them vary between 0 to 16,000 us/cm (non-saline to high saline) as shown in Figures 11-15. Only sample of dry season from sampling site 12 in Non Sung district (Figure 13), EC value rises up to be almost 30,000 us/cm (extremely high saline).

Referring to categorized of water, using total dissolved solids content by Freeze and Cherry, (1979), values of TDS in groundwater samples of rainy season in Figure 4.11 to 4.15 mostly are 100 to 4,000 ppm which can be considered as fresh to brackish water. Where TDS in dry season of 200 to 15,000 ppm are considered to be brackish to saline water.

The total dissolved solids are the total amount of mobile charged ions, including minerals, salts or metals dissolved in water. The electrical conductivity is an ability to allow the transport of an electric charge by ions. Therefore, the electrical conductivity value varies accordingly to the total dissolved solid value. The highest value of total dissolved solids is the same location as the highest value of electrical conductivity.

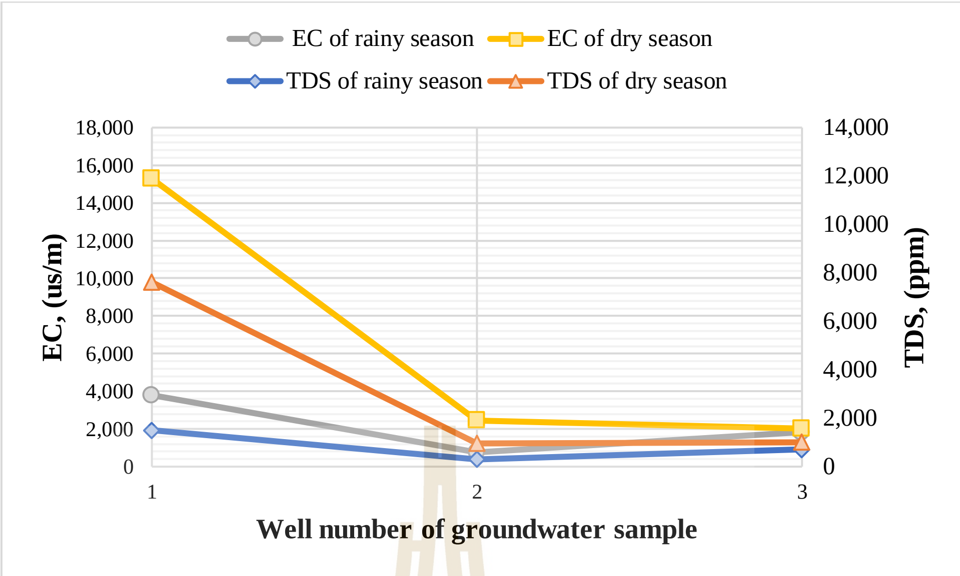


Figure 4.11 The electrical conductivity (EC) and total dissolved solids (TDS) of groundwater samples at Non Daeng district.

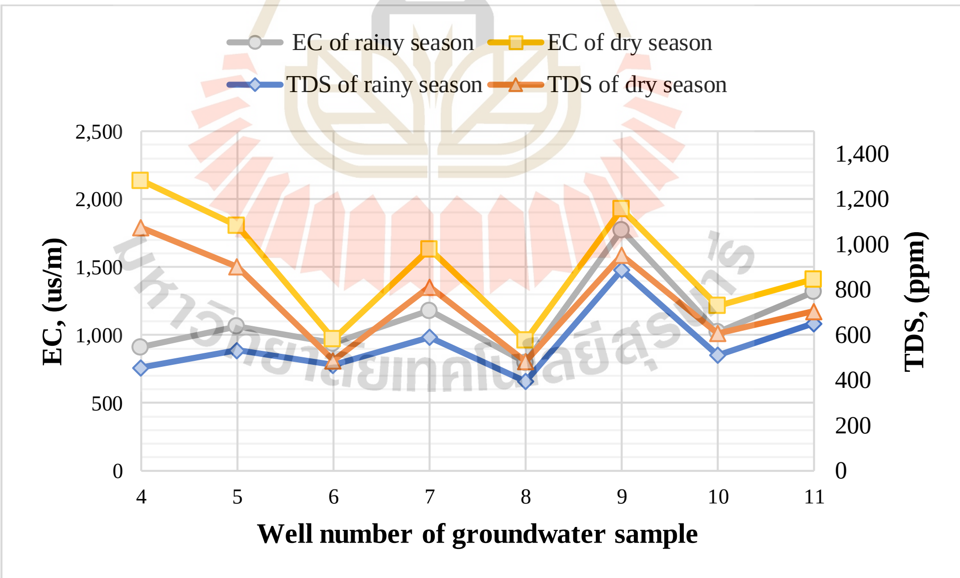


Figure 4.12 The electrical conductivity (EC) and total dissolved solids (TDS) of groundwater samples at Non Thai district.

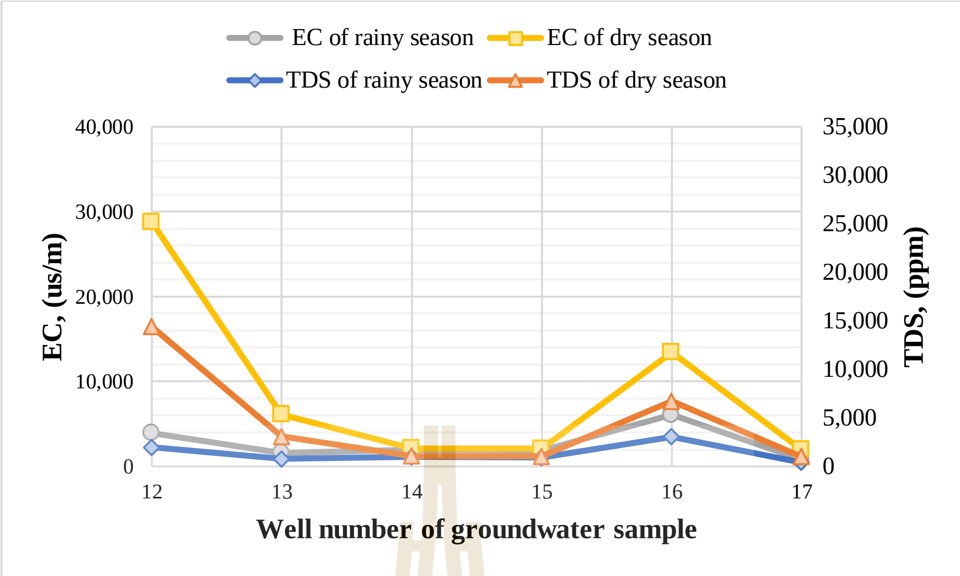


Figure 4.13 The electrical conductivity (EC) and total dissolved solids (TDS) of groundwater samples at Non Sung district.

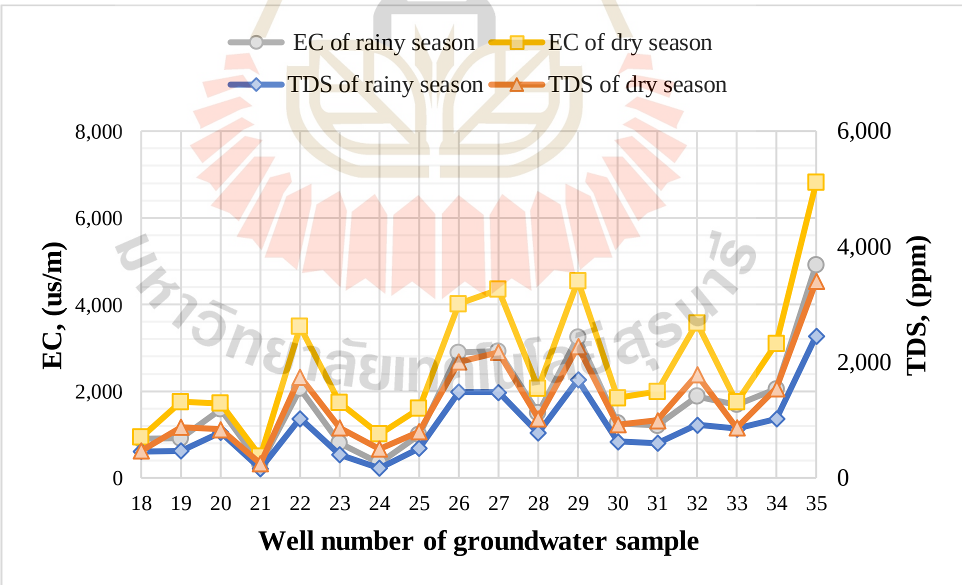


Figure 4.14 The electrical conductivity (EC) and total dissolved solids (TDS) of groundwater samples at Khong district.

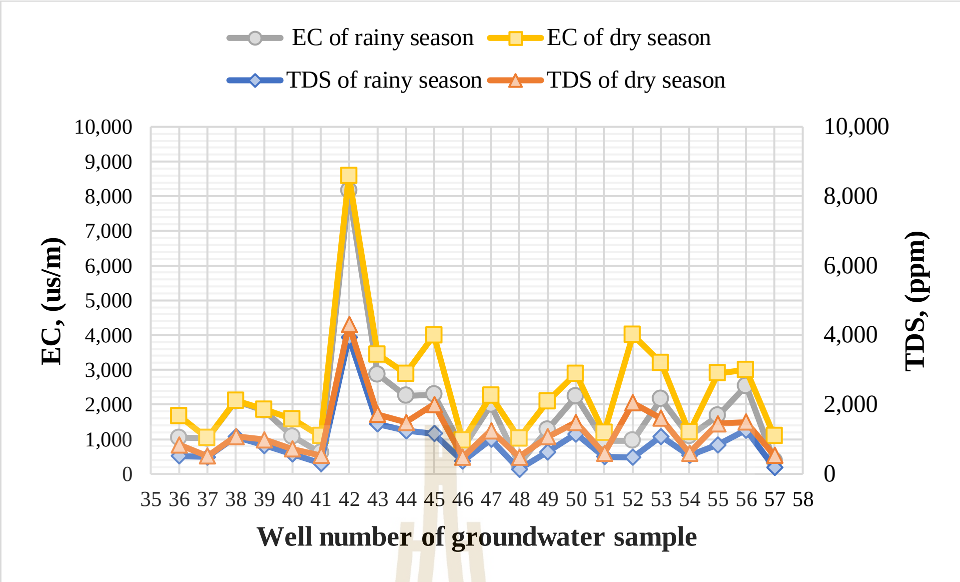


Figure 4.15 The electrical conductivity (EC) and total dissolved solids (TDS) of groundwater samples at Kham Sakae Saeng district.

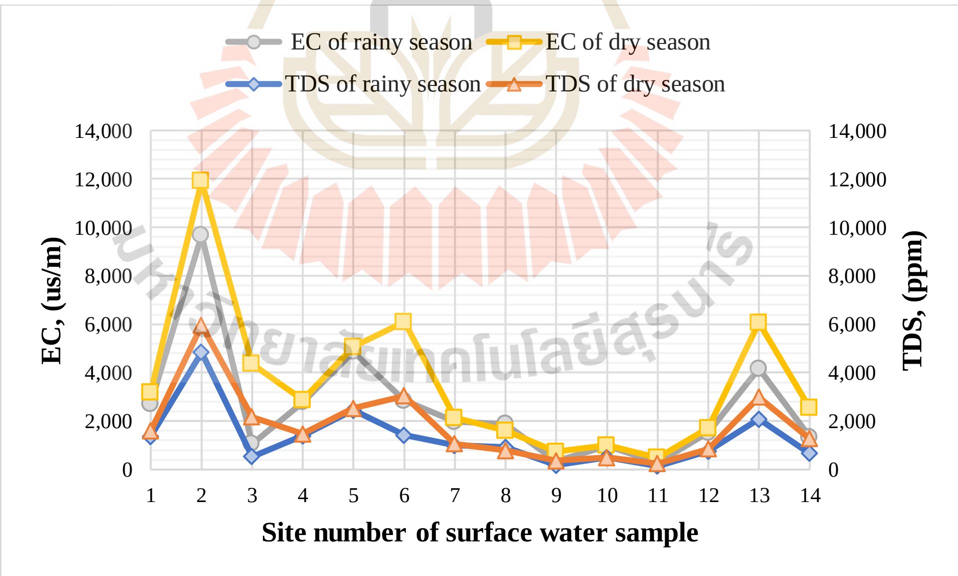


Figure 4.16 The electrical conductivity (EC) and total dissolved solids (TDS) of surface water samples.

- Analytical results of surface water samples

Only 14 samples of surface water were taken from the 5 districts. Their locations of sampling sites were described in Table 3.3. In Figure 4.16, EC values varies from 400 us/cm (non-saline) to more than 10,000 us/cm (high saline) in samples, picking in dry season. In rainy season, EC values are lower by changing in between 400 us/cm to more than 4,000 us/cm (moderate saline). Conclusively, most of the groundwater and surface water in study area are not suitable for consumption.

4.2.3 Salinity and Chloride content

The results of the salinity and chloride contents in the soil, groundwater, and surface water samples are coincidentally displayed as charts in Figures 4.17 to 4.27. Water is considered fresh or non-saline if salinity is less than 0.5 ppt and is considered very saline, like seawater, if salinity is higher than 35 ppt. Hence, brackish water is water with salinity above 0.5 ppt but below 35 ppt.

Analytical results of salinity and chloride contents will be discussed according to types of sample as follows.

- Analytical results of soil samples

Values of salinity and chloride contents correspondingly vary along well in both seasons (Figures 4.17 to 4.21). Of which, dry season sample contents are higher than rainy season.

Salinity contents in all rainy season samples are lower than 35 ppt. While, salinity contents in few dry season samples are higher than 35 ppt.

Chloride contents in soil samples of dry season showed extremely high values, caused by evaporation of groundwater and surface water, leaving salts accumulated on topsoil. The corresponding results of salinity and chloride contents again confirm that chloride content is an index of salinity.

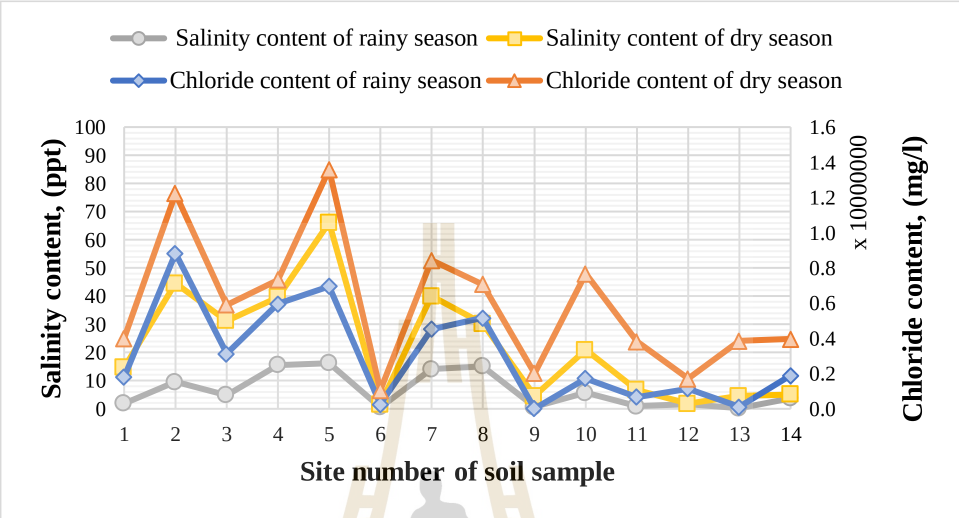


Figure 4.17 The salinity content and chloride content of soil samples at Non Daeng district.

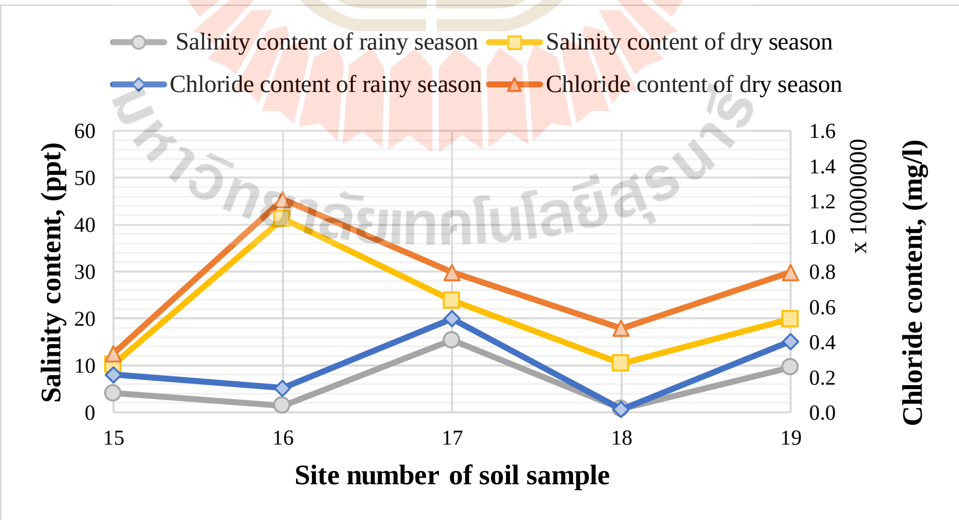


Figure 4.18 The salinity content and chloride content of soil samples at Non Thai district.

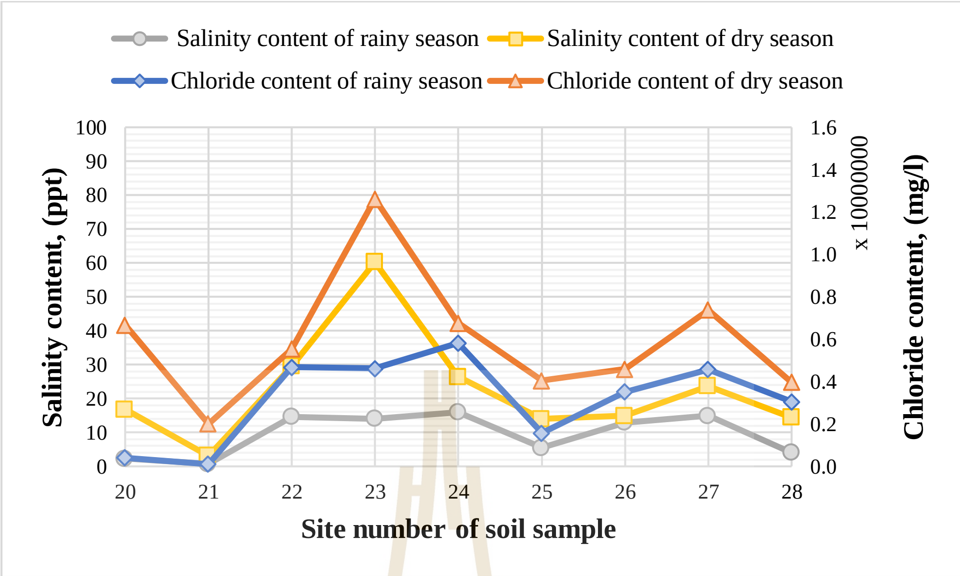


Figure 4.19 The salinity content and chloride content of soil samples at Non Sung district.

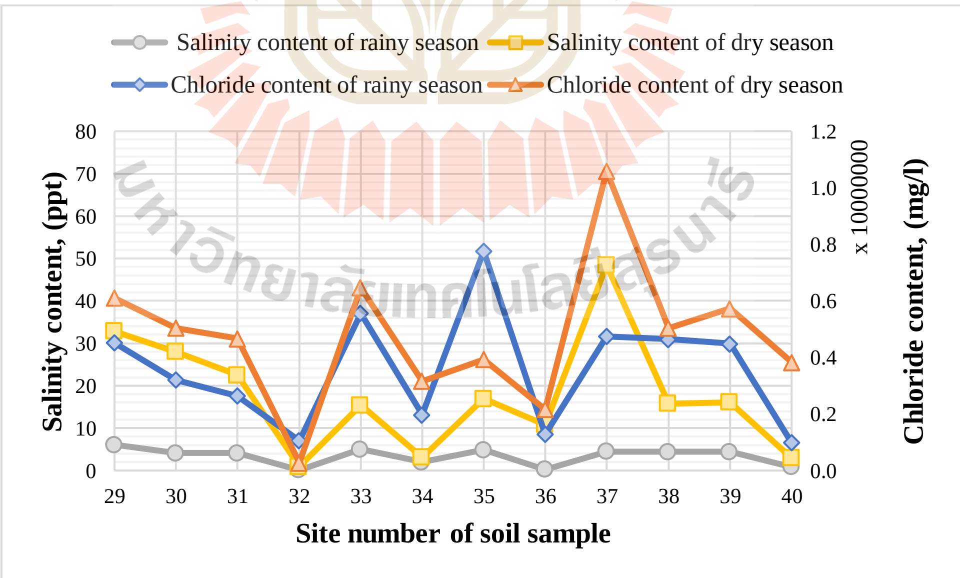


Figure 4.20 The salinity content and chloride content of soil samples at Khong district.

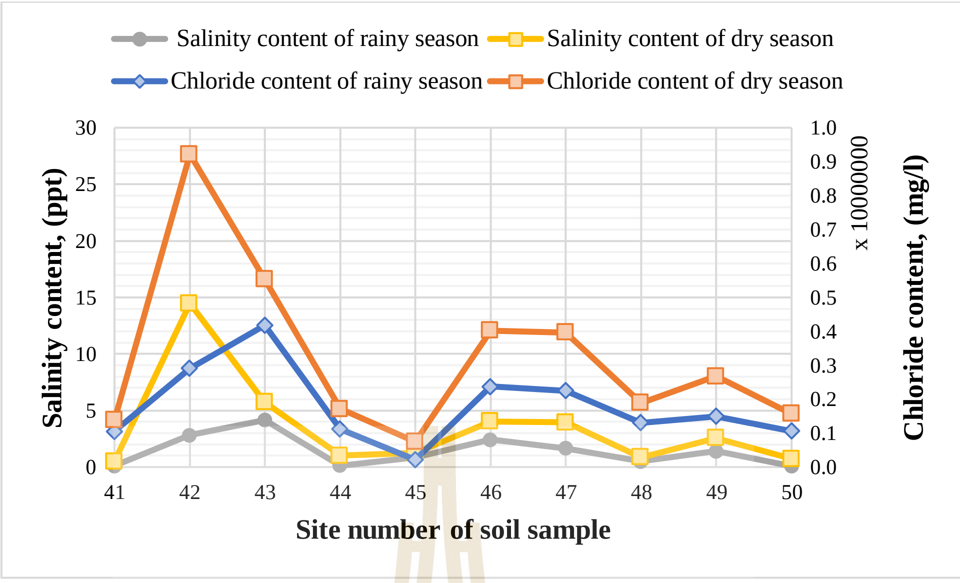


Figure 4.21 The salinity content and chloride content of soil samples at Kham Sakae Saeng district.

- Analytical results of groundwater samples

Values of salinity and chloride contents correspondingly vary along well in both seasons (Figures 4.22 to 4.26). Evidently, dry season sample contents are higher than rainy season.

Salinity contents in both rainy season and dry season samples are lower than 35 ppt with few contents are lower than 0.5 ppt. Therefore, groundwater quality in the study area are mostly brackish.

Chloride contents in groundwater samples of both seasons vary in range below 10,000 mg/l. Except at sample site 1, the value is as high as 25,000 mg/l.

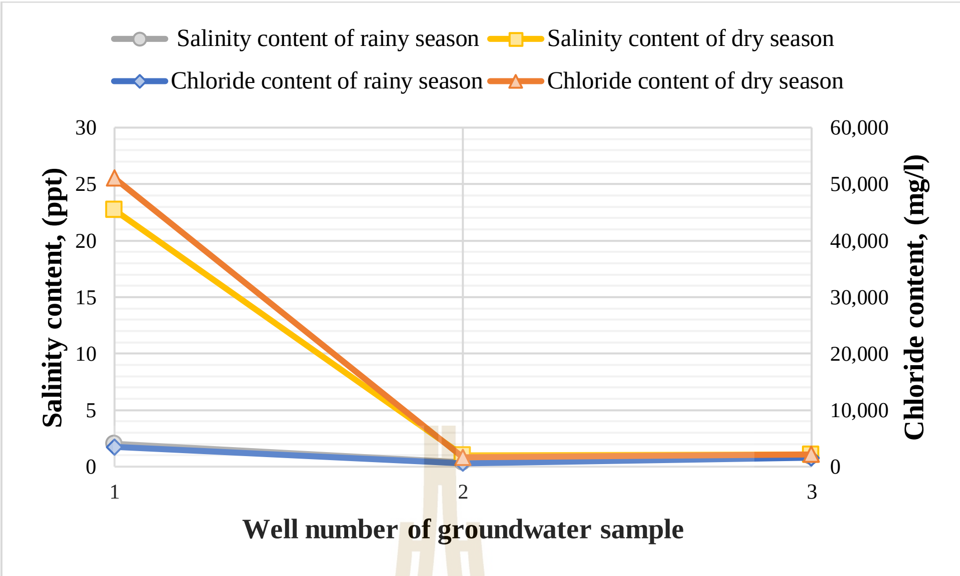


Figure 4.22 The salinity content and chloride content of groundwater samples at Non Daeng district.

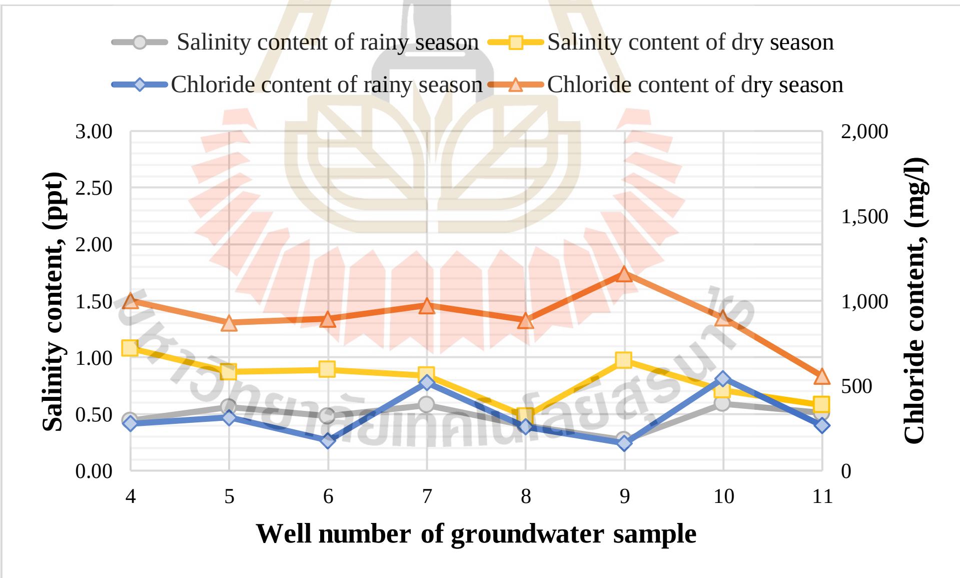


Figure 4.23 The salinity content and chloride content of groundwater samples at Non Thai district.

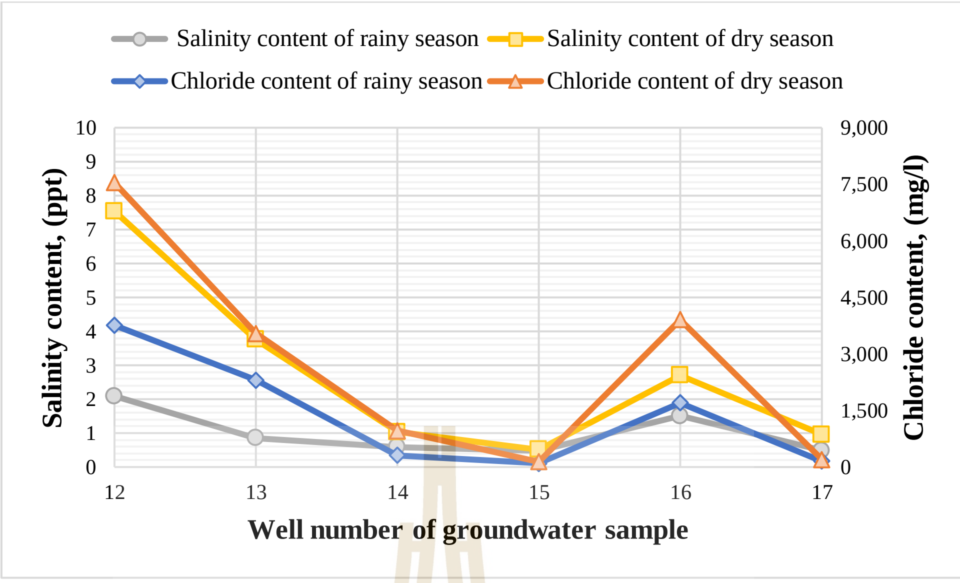


Figure 4.24 The salinity content and chloride content of groundwater samples at Non Sung district.

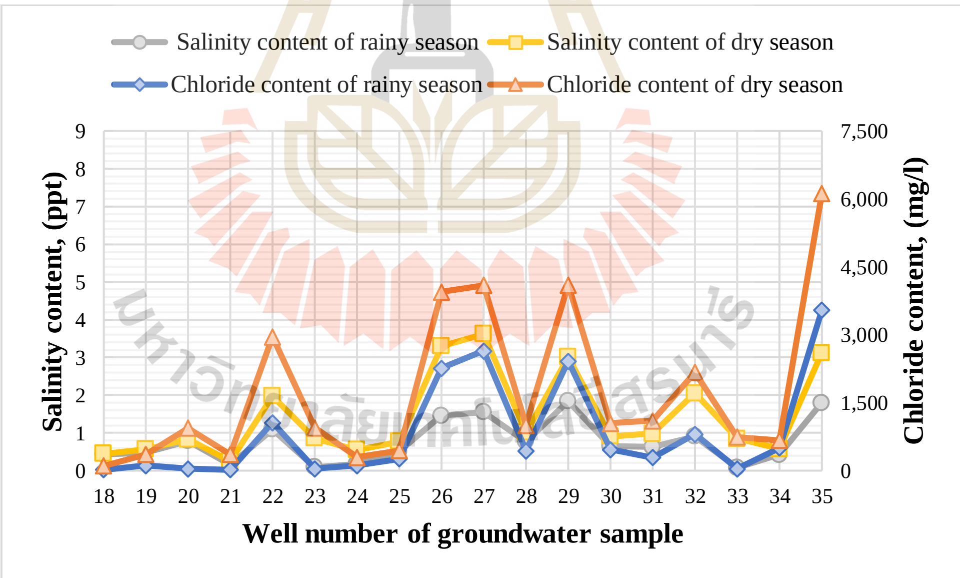


Figure 4.25 The salinity content and chloride content of groundwater samples at Khong district.

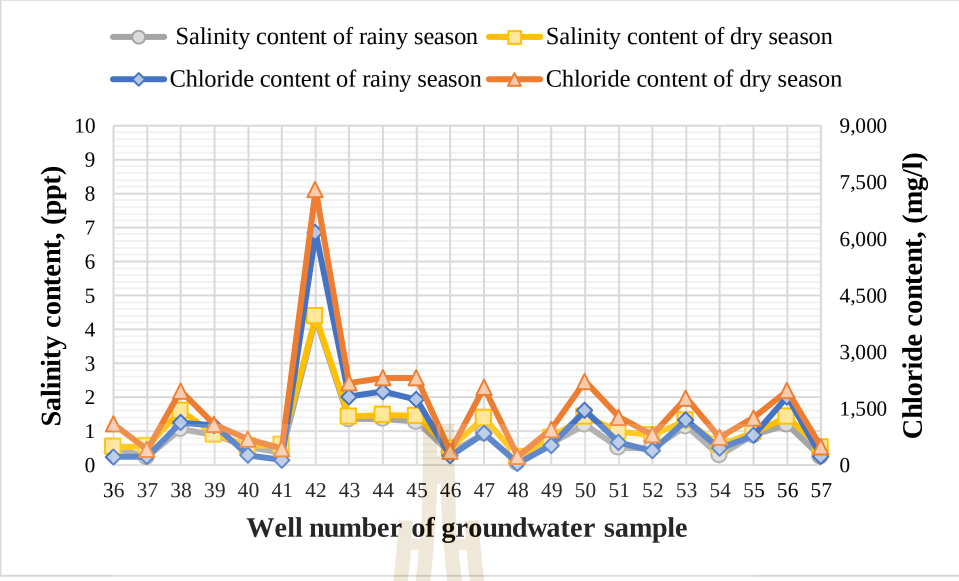


Figure 4.26 The salinity content and chloride content of groundwater samples at Kham Sakae Saeng district.

- Analytical results of surface water samples

Values of salinity and chloride contents correspondingly vary along well in both seasons (Figure 4.27). Evidently, dry season sample contents are higher than rainy season.

Salinity contents in both rainy season and dry season samples are lower than 35 ppt. Except at sample sites 10 and 11 are lower than 0.5 ppt. Therefore, groundwater quality in the study area are mostly brackish.

Chloride contents in surface water samples of both seasons vary in range below 22,000 mg/l.

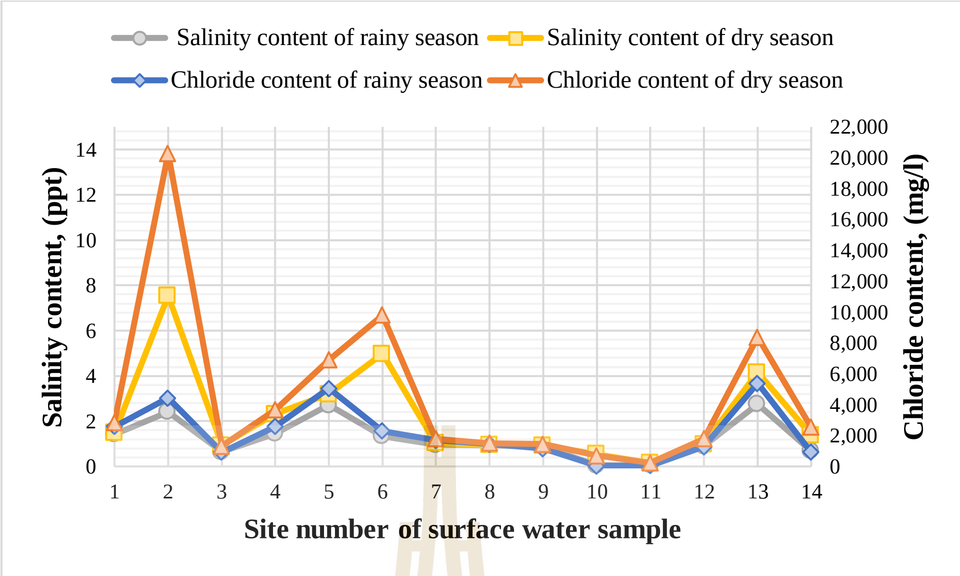


Figure 4.27 The salinity content and chloride content of surface water sample.

All chemical properties of samples were displayed in Appendix A.

4.3 X-ray diffractometer (XRD) analysis

Interpreataion of X-ray diffractometer analysis of 36 soil samples were displayed in Appendix B. The mineral compositions of soil samples within each district were averaged and listed as seen in Table 4.1. The highest mineral composition of quartz (SiO_2) can be simply described as the study area is covered by loose sandy soil. Minor components are muscovite ($KAl_2(AlSi_3)O_{10}(OH)_2$), kaolinite ($Al_2Si_2O_5(OH)_4$), calcite (CaCO3), gypsum ($CaSO_4.2H_2O$), halite (NaCl), magnetite (Fe_3O_4), sylvite (KCl), hematite (Fe_2O_3), and anhydrite ($CaSO_4$).

Table 4.1 The summary of mineral compositions in 5 districts.

District	Quartz	Muscovite	Kaolinite	Calcite	Halite	Sylvite	Gypsum	Anhydrite	Magnetite	Hematite
Non Daeng	86.03	5.23	2.64	1.18	0.26	0.07	0.31	0.03	0.25	0.06
Non Thai	79.81	6.23	2.01	2.81	0.24	0.04	0.16	-	0.31	0.06
Non Sung	86.21	5.13	3.10	0.61	0.35	0.08	0.39	-	0.17	0.03
Khong	84.02	5.22	2.86	1.86	0.26	0.06	0.36	0.09	0.21	0.06
Kham Sakae Saeng	87.44	4.86	2.85	0.01	0.15	0.09	0.49	0.03	0.17	0.04
Maximum	87.44	6.23	3.10	2.81	0.35	0.09	0.49	0.09	0.31	0.06
Minnimum	79.81	4.86	2.01	0.01	0.15	0.04	0.16	0.03	0.17	0.03
Average	84.70	5.33	2.69	1.29	0.25	0.07	0.34	0.05	0.22	0.05

4.4 X-ray fluorescence (XRF) analysis

The X-ray fluorescence analysis are determined as percent by weight of metal oxides content. The results of XRF analyses of soil samples were listed as seen in Appendix C. Among 22 components, which were analysed, the main components are SiO_2, Al_2O_3, K_2O, Na_2O, CaO, Cl, SO_3, and Fe_2O_3. The averaged values of each component in each district were displayed in Table 4.2. The highest content of SiO2 correspond well with amount of quartz content and other silicate minerals, analysed by XRD method.

Table 4.2 The percent by weight of compounds in 5 districts.

District	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3
Non Daeng	0.074	0.000	0.302	64.194	0.620	0.296	3.719	1.801	7.280	6.810	0.023
Non Thai	0.020	0.012	0.725	63.738	0.700	0.216	3.007	1.600	12.778	3.966	0.000
Non Sung	0.021	0.033	1.354	61.327	0.875	0.209	4.544	1.319	11.948	3.501	0.000
Khong	0.056	0.044	1.698	70.061	0.519	0.316	2.425	1.041	8.714	2.053	0.012
Kham Sakae Saeng	0.055	0.064	2.138	77.860	1.092	1.323	2.077	2.338	6.990	1.712	0.000
Maximum	0.074	0.064	2.138	77.860	1.092	1.323	4.544	2.338	12.778	6.810	0.023
Minnimum	0.020	0.000	0.302	61.327	0.519	0.209	2.077	1.041	6.990	1.712	0.000
Average	0.045	0.031	1.244	67.436	0.761	0.472	3.154	1.620	9.542	3.608	0.007

Table 4.2 (Continued) The percent by weight of compounds in 5 districts.

District	MnO	Fe_2O_3	Co_3O_4	NiO	ZrO_2	PbO	Cs_2O	CuO	BaO	CeO_2	HfO_2	Total
Non Daeng	0.727	13.045	0.015	0.000	0.029	0.000	1.023	0.000	0.044	0.000	0.000	100.00
Non Thai	0.947	11.531	0.016	0.000	0.035	0.000	0.660	0.000	0.049	0.000	0.000	100.00
Non Sung	0.987	13.107	0.042	0.017	0.052	0.149	0.251	0.014	0.187	0.064	0.000	100.00
Khong	0.559	11.998	0.000	0.000	0.144	0.093	0.267	0.000	0.000	0.000	0.000	100.00
Kham Sakae Saeng	0.178	4.062	0.000	0.000	0.089	0.000	0.000	0.000	0.000	0.022	0.000	100.00
Maximum	0.987	13.107	0.042	0.017	0.144	0.149	1.023	0.014	0.187	0.064	0.000	100.00
Minnimum	0.178	4.062	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Average	0.679	10.749	0.015	0.003	0.070	0.048	0.440	0.003	0.056	0.017	0.000	100.00

4.5 Flame Atomic Absorption Spectrometer (FAAS) analysis

All of soil, and surface water samples were analysed for atomic contents by Atomic Absorption Spectrometer (FAAS) analysis. Locations of the soil samples were previously listed in Table 3.1. Out of total 57 ground water wells, only 10 wells with samples containing abnormally high chemical compositions were selected for Flame Atomic Absorption Spectrometer (FAAS) analysis. Locations of selected groundwater wells were listed as seen in Table 4.3. Remarkably, well numbers from the same locations in this table are different from numbers in Table 3.2. In the same manner, only 10 surface water sampling sites were selected out of totally 14 sampling sites. Locations of sampling sites were listed as seen in Table 4.4. Analyses by Flame Atomic

Absorption Spectrometer Analysis (FAAS) were undertaken to determine calcium, magnesium, potassium, iron and sodium ion contents. The analytical results were displayed in Appendix D.

Table 4.3 Locations of groundwater samples, selected for Flame Atomic Absorption Spectrometer Analysis (FAAS).

Well	District	Sub district	UTM E	UTM N	Well No.	Location
1	Non Daeng	Non Daeng	238141	1706668	5705D031	Non Daeng Municipal school
2	Non Daeng	Non Daeng	238343	1705364	5405B007	Phu Wittaya school
3	Non Thai	Banlang	170357	1688964	-	Ban Muang Kao 2
4	Non Thai	Makha	187792	1689952	MG1571	Nong Doom health promoting hospital
5	Non Sung	Than Prasat	222250	1687690	-	Ban Talad Kae
6	Non Sung	Tanot	206821	1671468	D0516	Ban Non Makok
7	Khong	Nong Bua	195999	1717793	MG679	Ban Nong Sakae school
8	Khong	Nong Bua	192508	1717165	5505G052	Ban Ta Kim
9	Kham Sakae Saeng	Non Mueang	189356	1706970	MY337	Ban Khum Muang
10	Kham Sakae Saeng	Nong Hua Fan	207082	1705864	MG1637	Ban Jod school

Table 4.4 Locations of surface water samples, selected for Flame Atomic Absorption Spectrometer Analysis (FAAS).

Site No.	District	Sub district	UTM E	UTM N	Location
1	Non Daeng	Non Daeng	231234	1710843	Non Ta Then reservoir
2	Non Daeng	Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting a hospital
3	Non Thai	Dan Chak	1678720	188274	Ban Dan Chak reservoir
4	Non Thai	Non Thai	183315	1680970	Don Bot temple reservoir
5	Non Sung	Bing	210826	1674312	Bing reservoir
6	Non Sung	Don Chomphu	215493	1682185	Lum Chiang Krai river (Ban Som)
7	Khong	Khu Khat	222394	1706686	Kud Vien reservoir
8	Khong	Mueang Khong	211620	1702627	Bueng Don Yai reservoir
9	Khong	Kham Sombun	221489	1700984	Non Si Fun reservoir
10	Kham Sakae Saeng	Kham Sakae Saeng	196920	1694693	Ban Bu La Kro reservoir
11	Kham Sakae Saeng	Kham Sakae Saeng	195785	1701679	Ban Yakha Non Jang school reservoir
12	Kham Sakae Saeng	Kham Sakae Saeng	197128	1703284	Non Lan canal

The ions concentration in soil, groundwater and surface water samples of dry season are generally higher than of rainy season (Figures 4.28 to 4.48).

Analytical results of Flame Atomic Absorption Spectrometer (FAAS) analysis are described as follows.

4.5.1 Soil samples

Unsurprisinly, ion contents of dry season samples are higher than rainy season, especially sodium ion contents. The highest content of more than 16,000 mg/l of Na+ clearly demonstrates that this study area is saline affected.

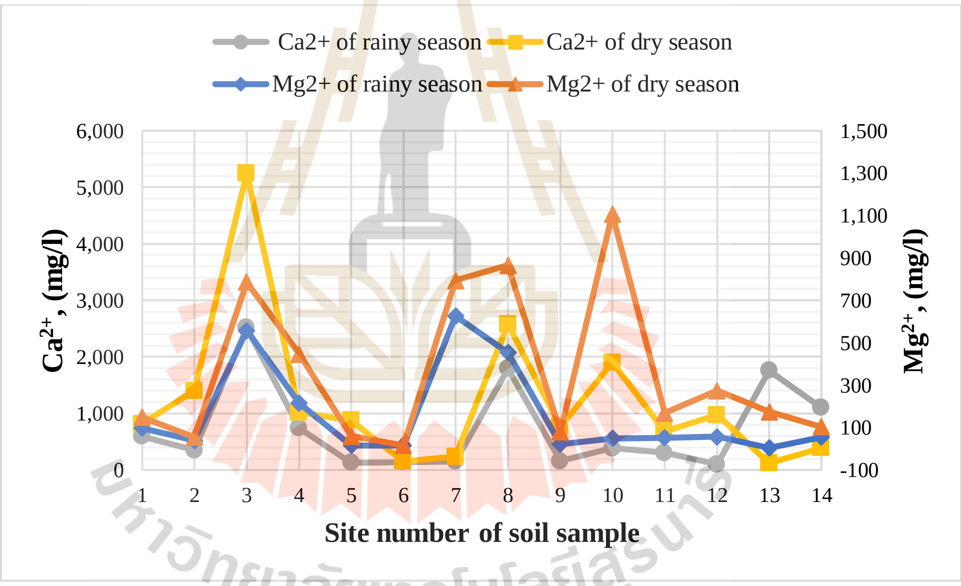


Figure 4.28 Contents of calcium and magnesium ions of soil samples at Non Daeng district.

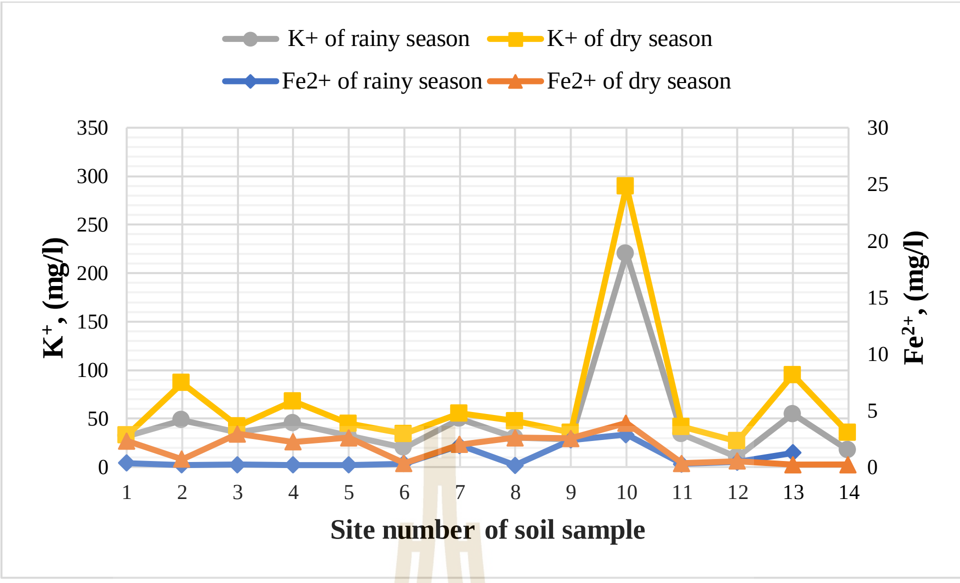


Figure 4.29 Contents of potassium and iron ions of soil samples at Non Daeng district.

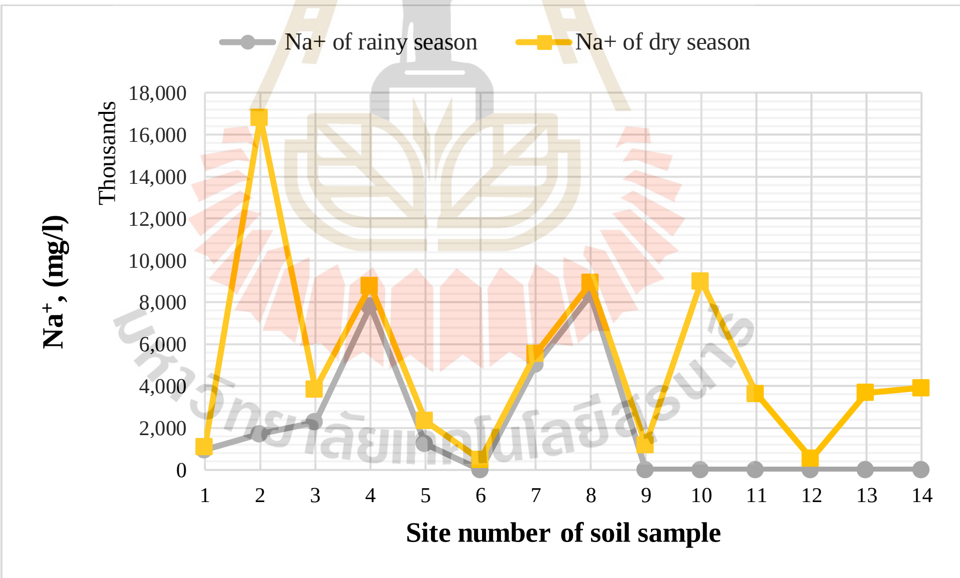


Figure 4.30 Contents of sodium ions of soil samples at Non Daeng district.

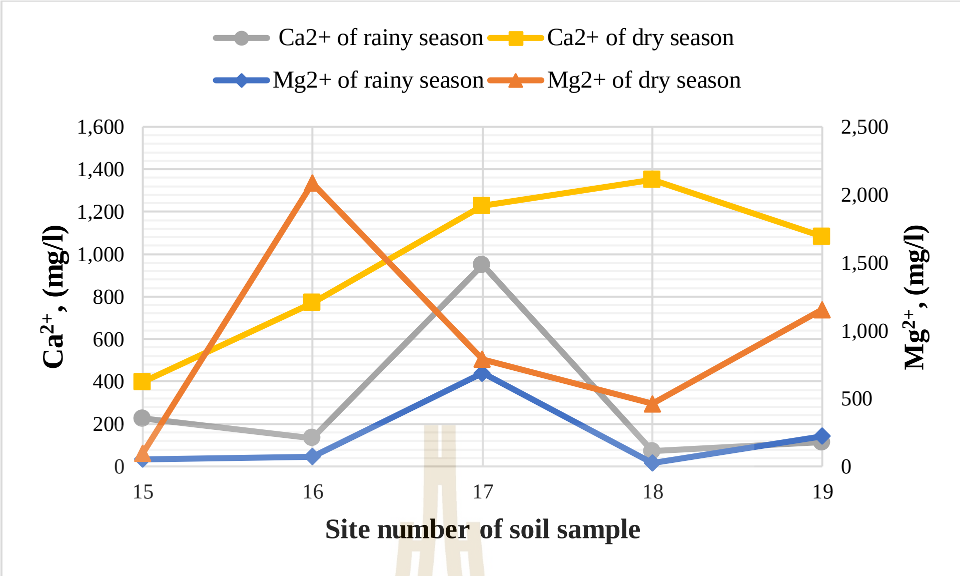


Figure 4.31 Contents of calcium and magnesium ions of soil samples at Non Thai district.

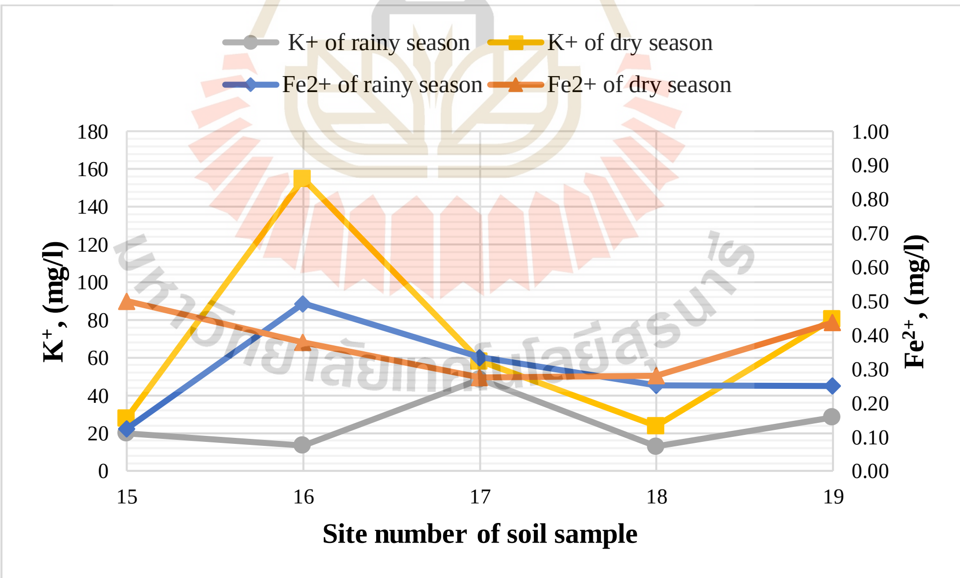


Figure 4.32 Contents of potassium and iron ions of soil samples at Non Thai district.

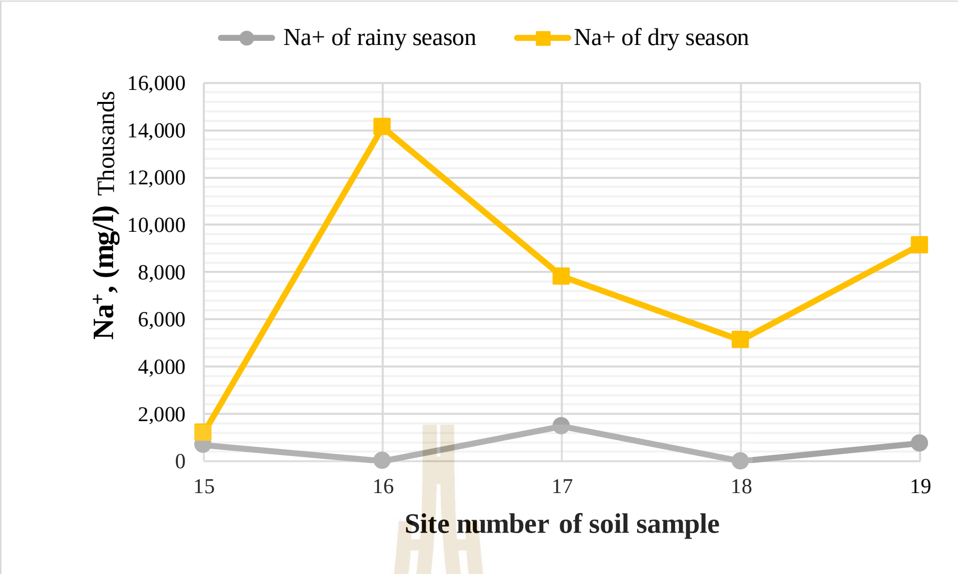


Figure 4.33 Contents of sodium ions of soil samples at Non Thai district.

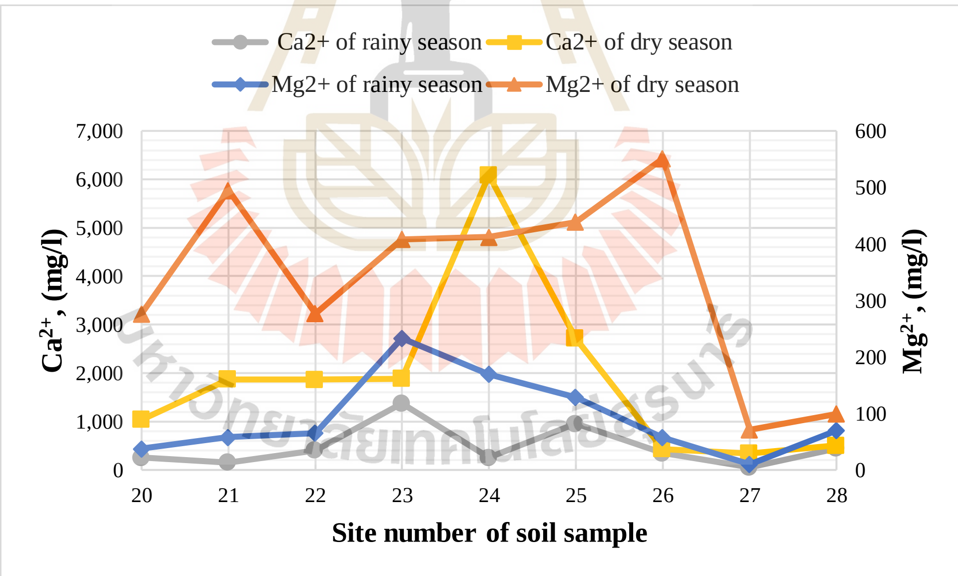


Figure 4.34 Contents of calcium and magnesium ions of soil samples at Non Sung district.

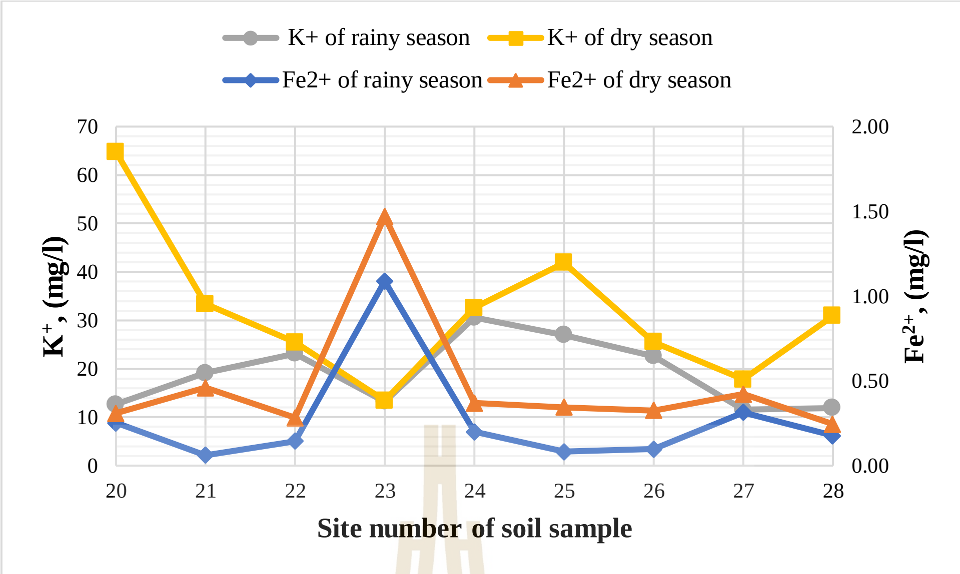


Figure 4.35 Contents of potassium and iron ions of soil samples at Non Sung district.

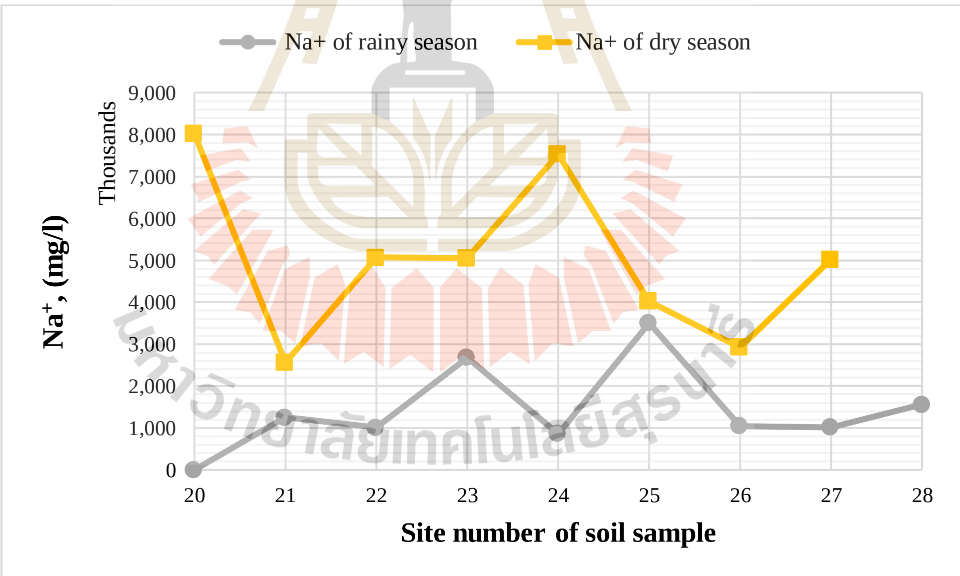


Figure 4.36 Contents of sodium ions of soil samples at Non Sung district.

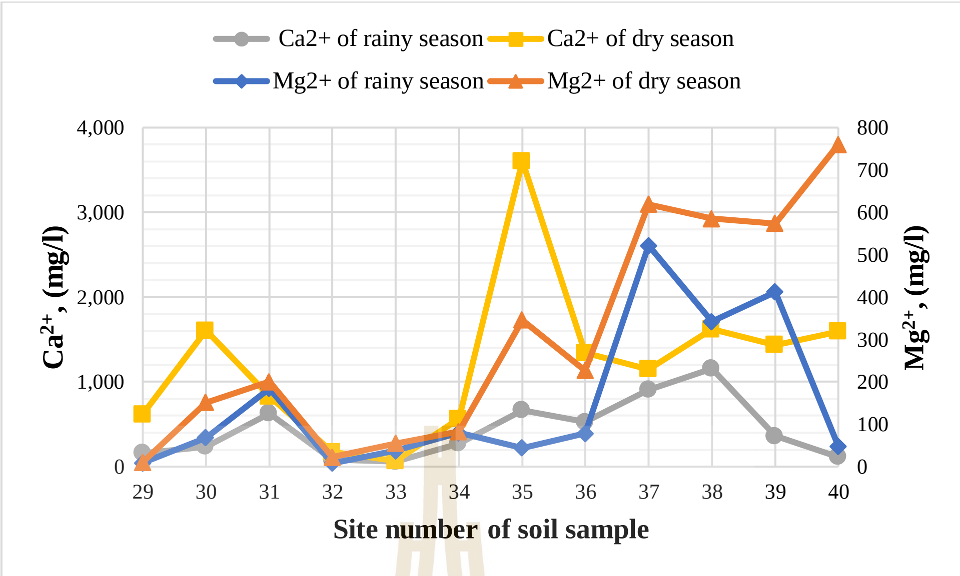


Figure 4.37 Contents of calcium and magnesium ions of soil samples at Khong district.

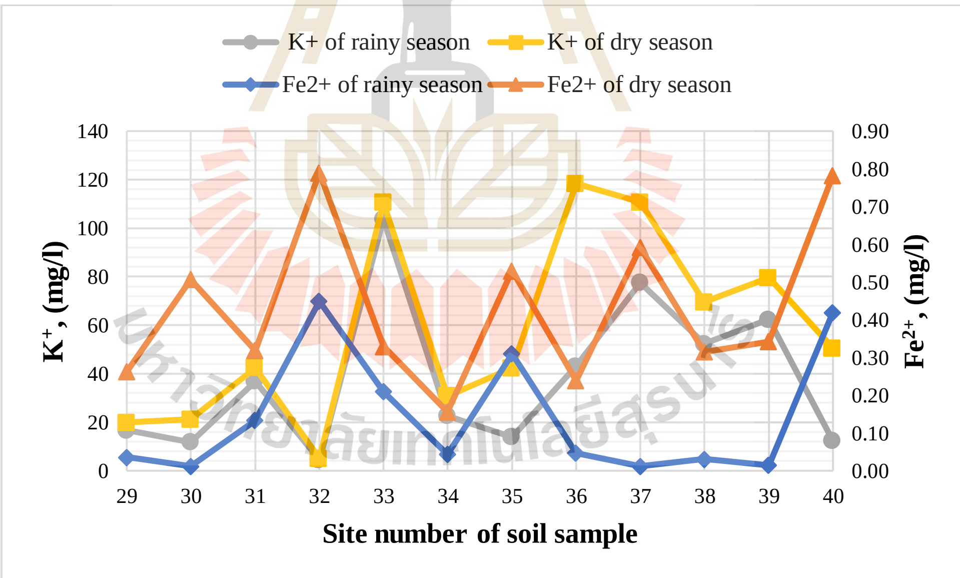


Figure 4.38 Contents of potassium and iron ions of soil samples at Khong district.

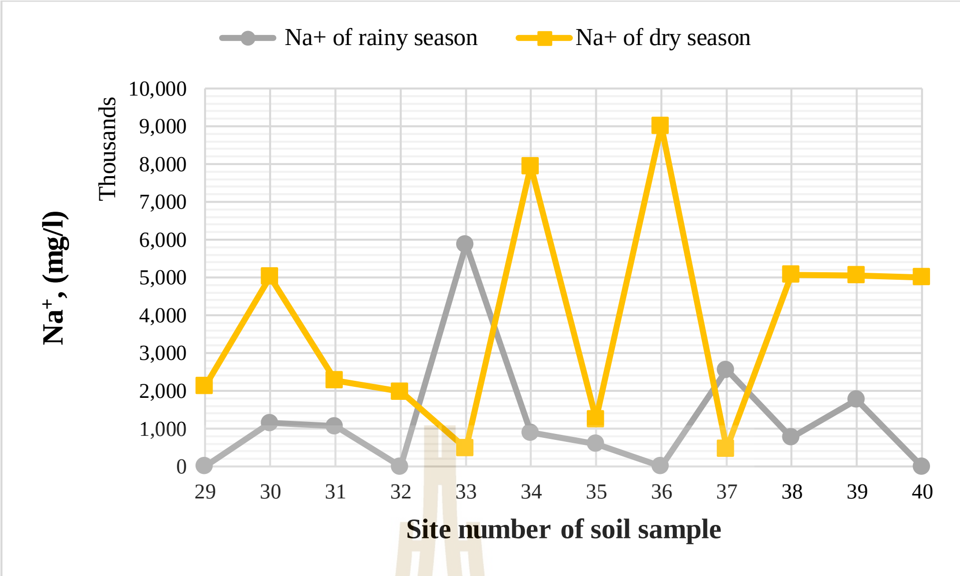


Figure 4.39 Contents of sodium ions of soil samples at Khong district.

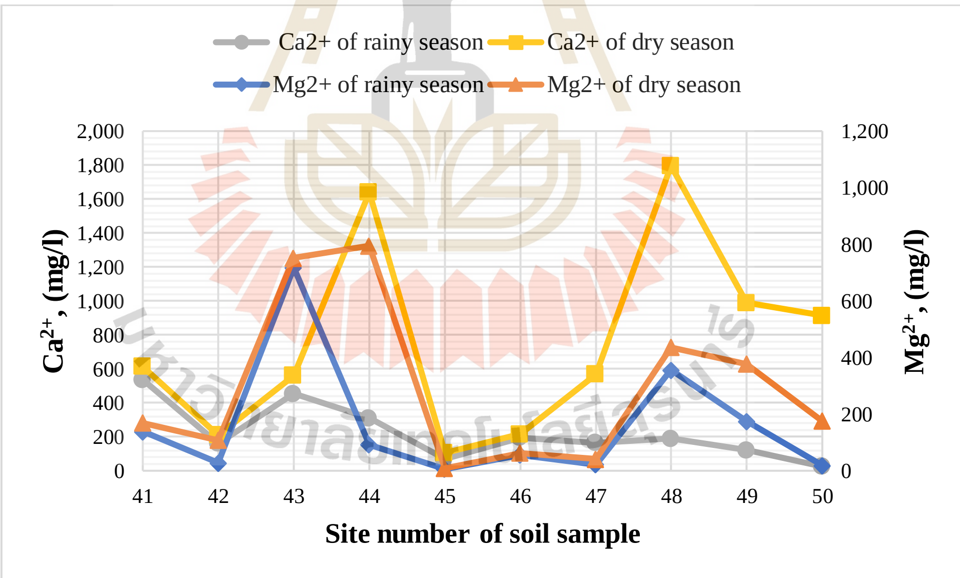


Figure 4.40 Contents of calcium and magnesium ions of soil samples at Kham Sakae Saeng district.

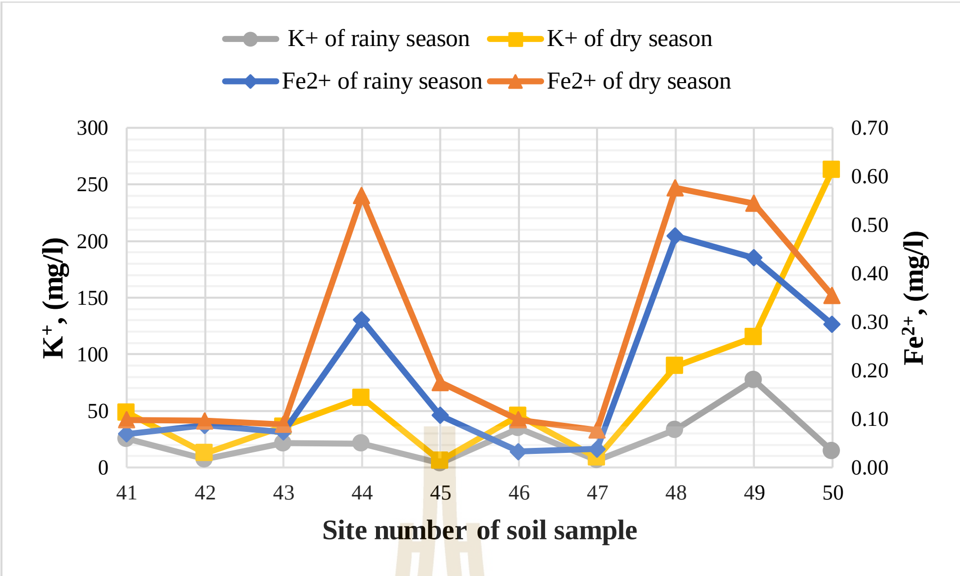


Figure 4.41 Contents of potassium and iron ions of soil samples at Kham Sakae Saeng district.

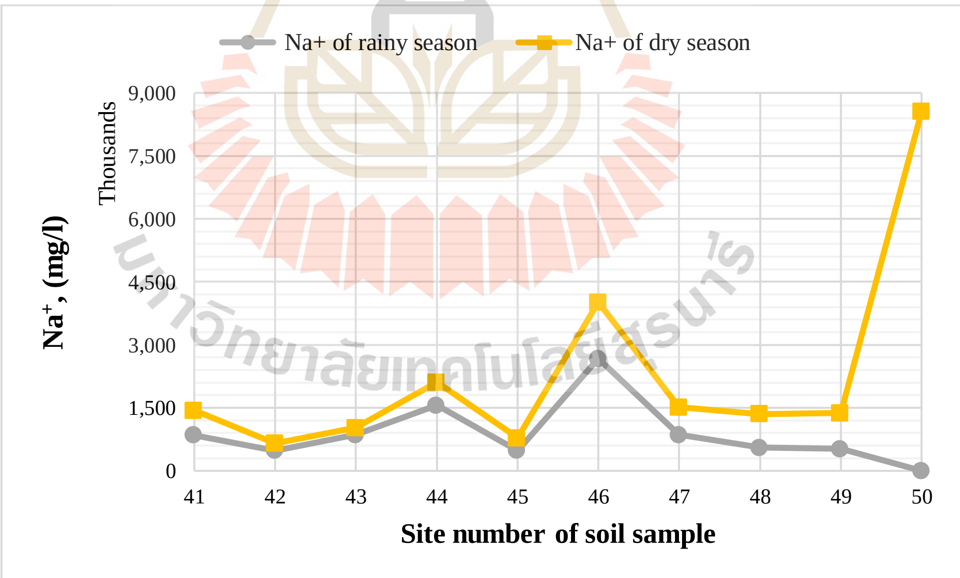


Figure 4.42 Contents of sodium ions of soil samples at Kham Sakae Saeng district.

4.5.2 Groundwater samples

Variation of ion concentrations in different locations are more regular in groundwater samples than soil samples. Eventhough, samples of dry season contain higher content than of rainy season. Ca2+, K+, and Na+ contents in sample site is extremely high.

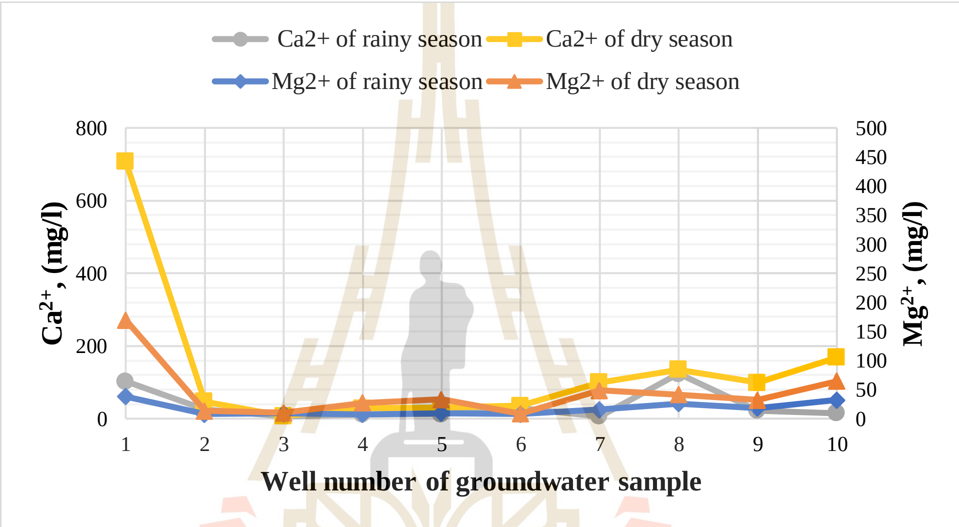


Figure 4.43 Contents of calcium and magnesium ions of groundwater samples.

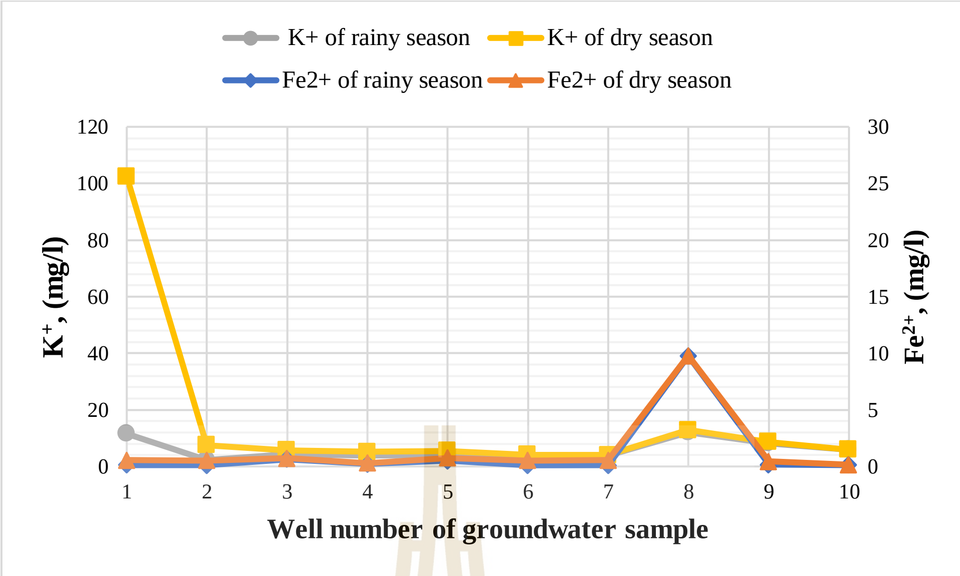


Figure 4.44 Contents of potassium and iron ions of groundwater samples

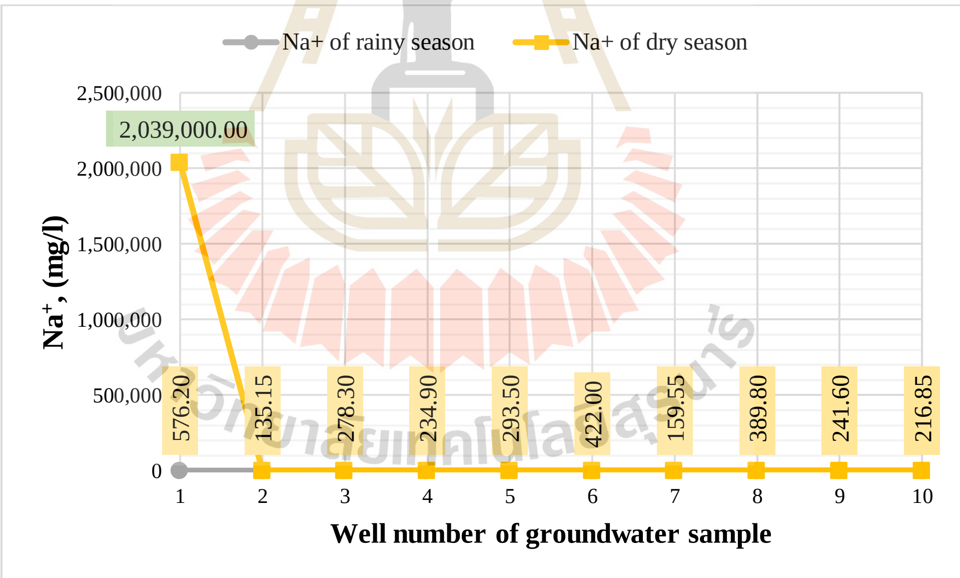


Figure 4.45 Contents of sodium ions of groundwater sample.

4.5.3 Surface water samples

Concentration of ions are all higher in dry season. Strangely, sampling site 11 seem to contain highest values of all ion contents except Na+ ion.

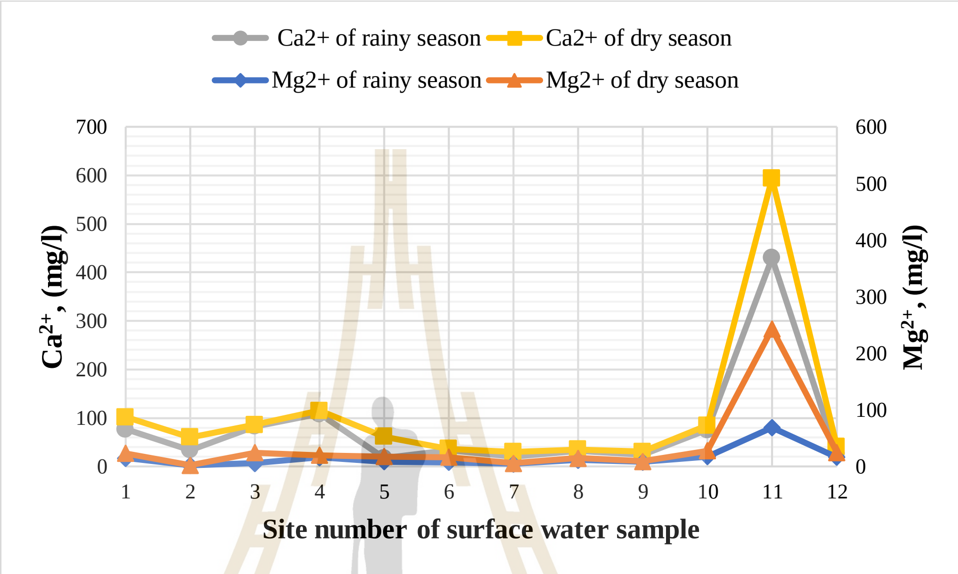


Figure 4.46 Contents of calcium and magnesium ions of surface water samples.

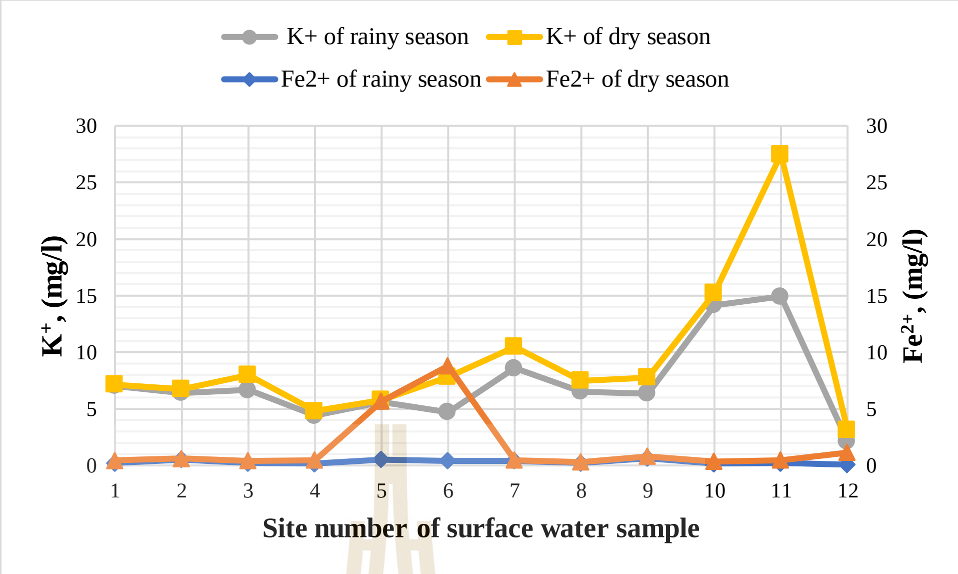


Figure 4.47 Contents of potassium and iron ions of surface water samples.

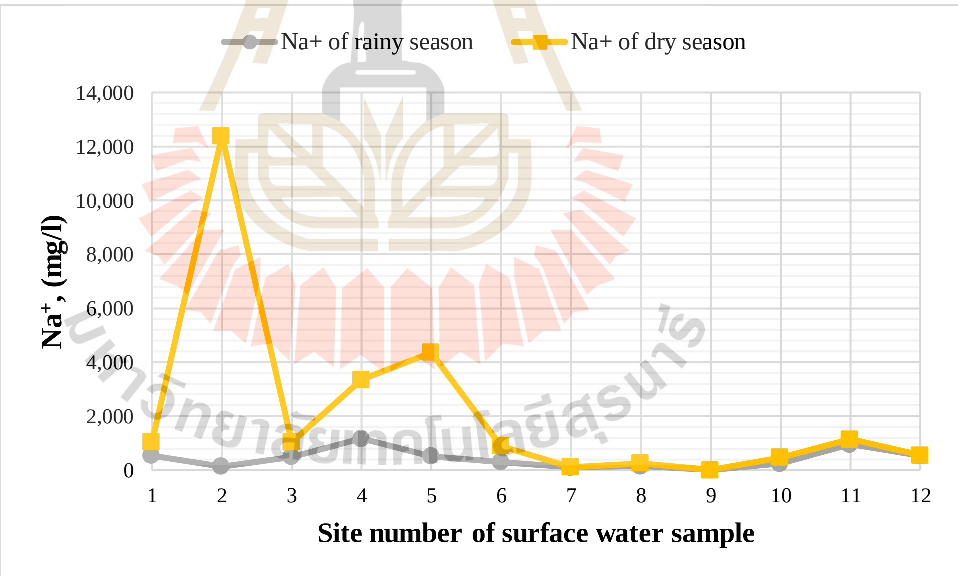


Figure 4.48 Contents of sodium ions of the surface water sample.

4.6 The distribution of salinity and chloride contents

Data of salinity and chloride contents in soil, groundwater and surface water samples, as shown in Appendix A, were interpolated and displayed as distribution maps, using ArcMap 10.3 program (Figures 4.49 to 4.60). Different classes of salinity and chloride contents were displayed by shades of different colors. Contour lines of topography and groundwater depth were also coincidentally drawn on the maps.

Discussions on distribution of salinity and chloride contents were made based on diffent types of samples as follows.

4.6.1 Soil samples

Aerial extension of salinity and chloride contents in rainy and dry seasons are similar, but only extension of dry season contents are greater (Figures 4.49 to 4.52).

There are roughly 4 areas of high values of salinity and chloride contents.

1) North of Non Thai district is located between elvations of 180 and 200 m. above MSL.
2) South of Non Sung district is located below elvations of is located between elvations of 180 and 200 m. above MSL.
3) South to east of Non Daeng connecting to east of Kong district is situated in area with elevation of 160 m. and lower.
4) Central part of Kong district is situated within area of elevation between 180 and 200 m. above MSL.

Notably, there are no areas of high contents within Kham Sakae Saeng district, which is rather high with elevation above 180 m and up to higher than 240 m. Thus, conclusion can be drawn that occurences of saline soil can occur in areas with elevation below 200 m. These saline soil areas may occur by groundwater seepage where saline groundwater seeps out and leaves soluble salt on surface soil.

4.6.2 Groundwater samples

Salinity and chloride contents indicate degree of groundwater and rock salt interaction with each other. In other words, saline groundwater indicates occurrence of rock salt in close vicinity to the ground water wells. Distribution patterns of salinity and chloride contents coincide well with each other even in different seasons (Figures 4.53 to 4.56). The same phenomena occurs that extension of distribution patterns are greater in maps of dry season samples. Water recharges to groundwater aquifer, making salinity and chloride contents to be lower in rainy season. High salinity and chloride areas can be identified as.

1) South of Non Sung district
2) East of Non Sung district
3) Central Non Daeng district
4) Central northern Khong district
5) West of Khong district
6) Northern Kham Sakae Saeng Khong district

4.6.3 Surface water samples

During rainy season, flash flood washes solubles salt from surface soil and bring them along down to surface water bodies. Soluble salts cause salinity in surface water. This phenomena gives the same results as occurring with surface soil as salt and chloride that were washed from high topography later accumulated in water bodies of lower topography. Distribution patterns of salinity contents in both rainy season and dry season are more or less the same. High salinity and chloride areas were recognized as (Figures 4.57 to 4.60).

1) Central Non Thai district
2) South of Non Sung district
3) Central Non Daeng district
4) West Kham Sakae Saeng district

It is clearly seen that in all three types of samples, contents of both salinity and chloride are higher and wider spread in dry season. Distribution patterns of sample contents are more similar between soil and surface water samples. Only difference is that no high values of salinity and chloride contents in soil samples of Kham Sakae Saeng district.

Notably, salinity contents in all sample types evidently showed saline affected area in Non Daeng district.

Relatively, distribution patterns of salinity and chloride contents in surface water are greater than in groundwater.

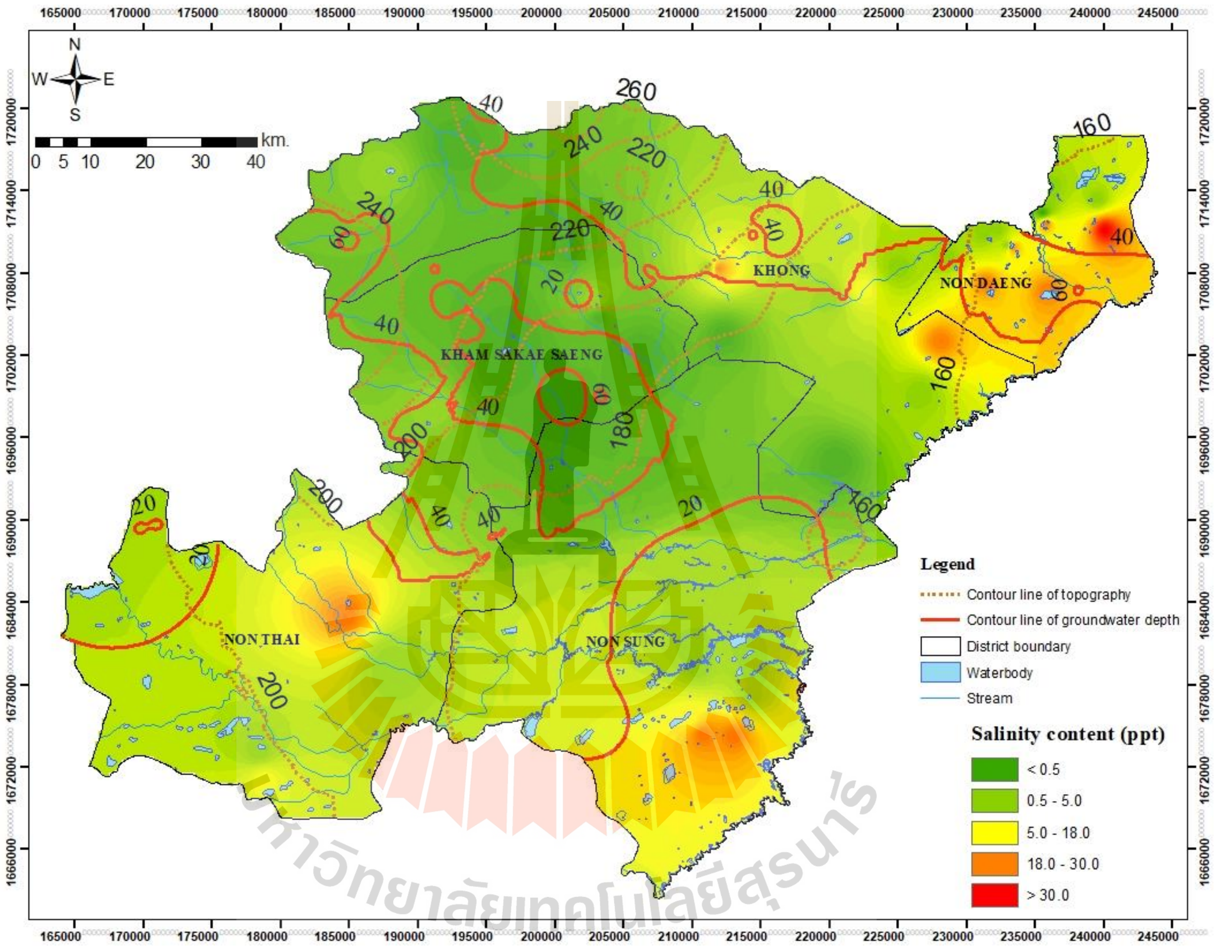


Figure 4.49 Map of salinity contents in soil samples of rainy season.

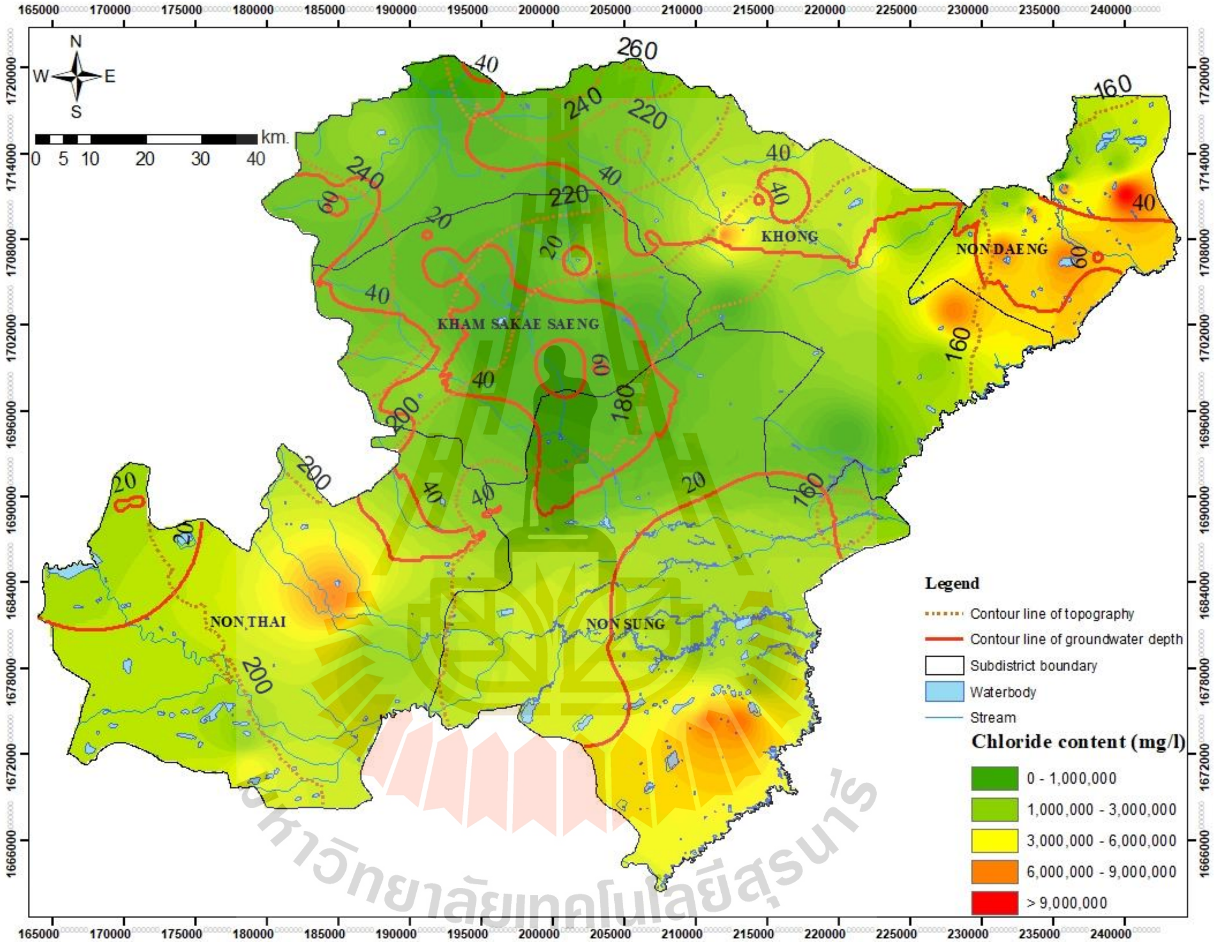


Figure 4.50 Map of chloride contents in soil samples of rainy season.

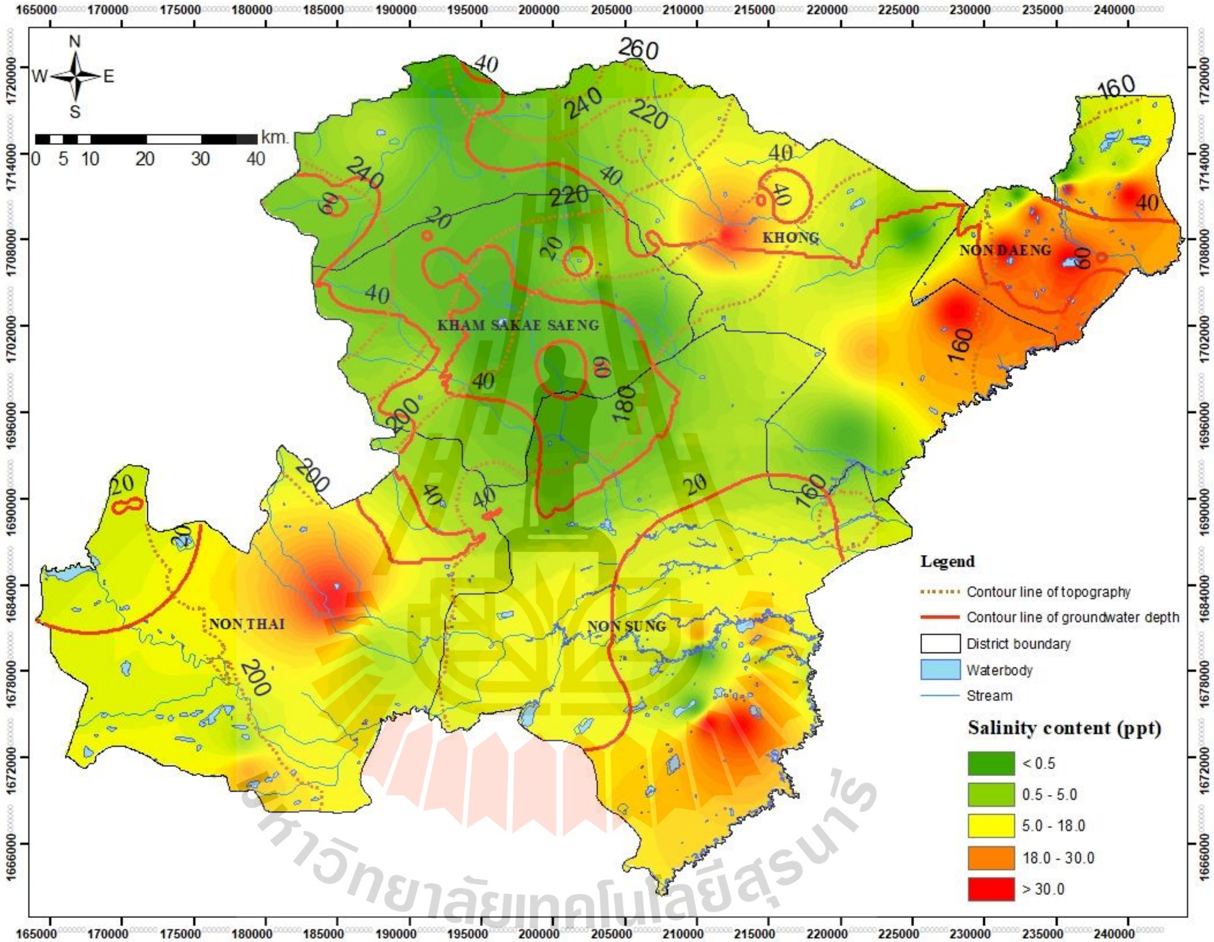


Figure 4.51 Map of salinity contents in soil samples of dry season.

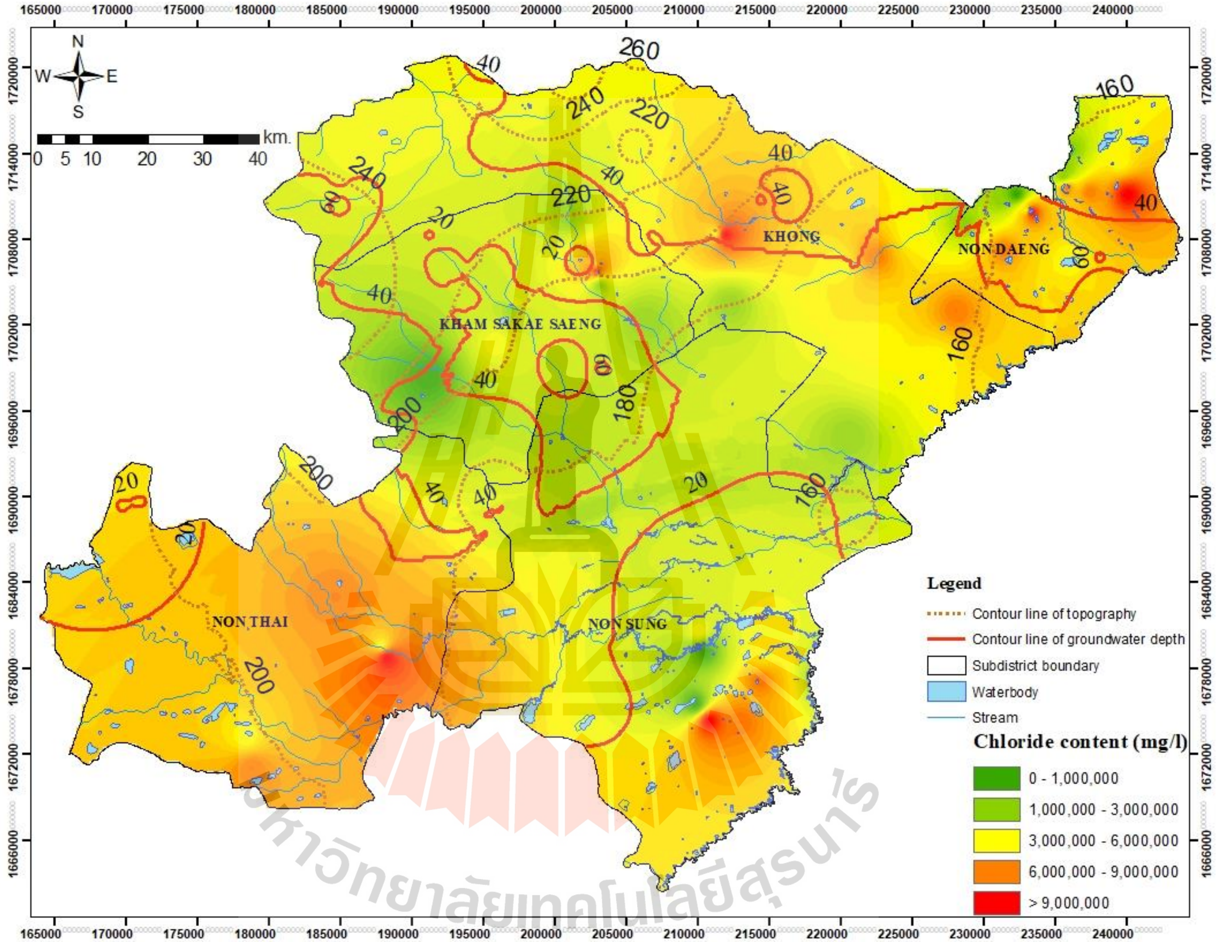


Figure 4.52 Map of chloride contents in soil samples of dry season.

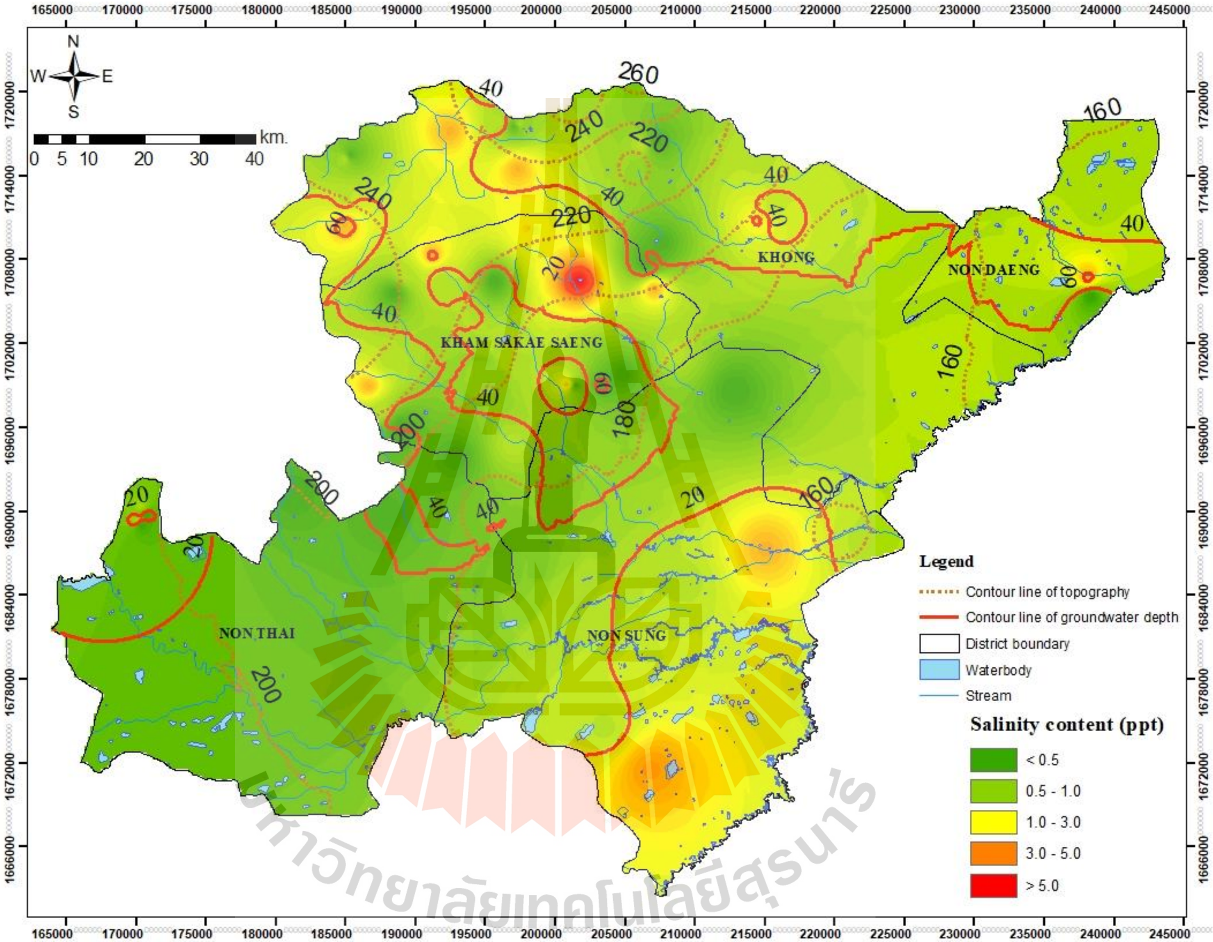


Figure 4.53 Map of salinity contents in groundwater samples of rainy season.

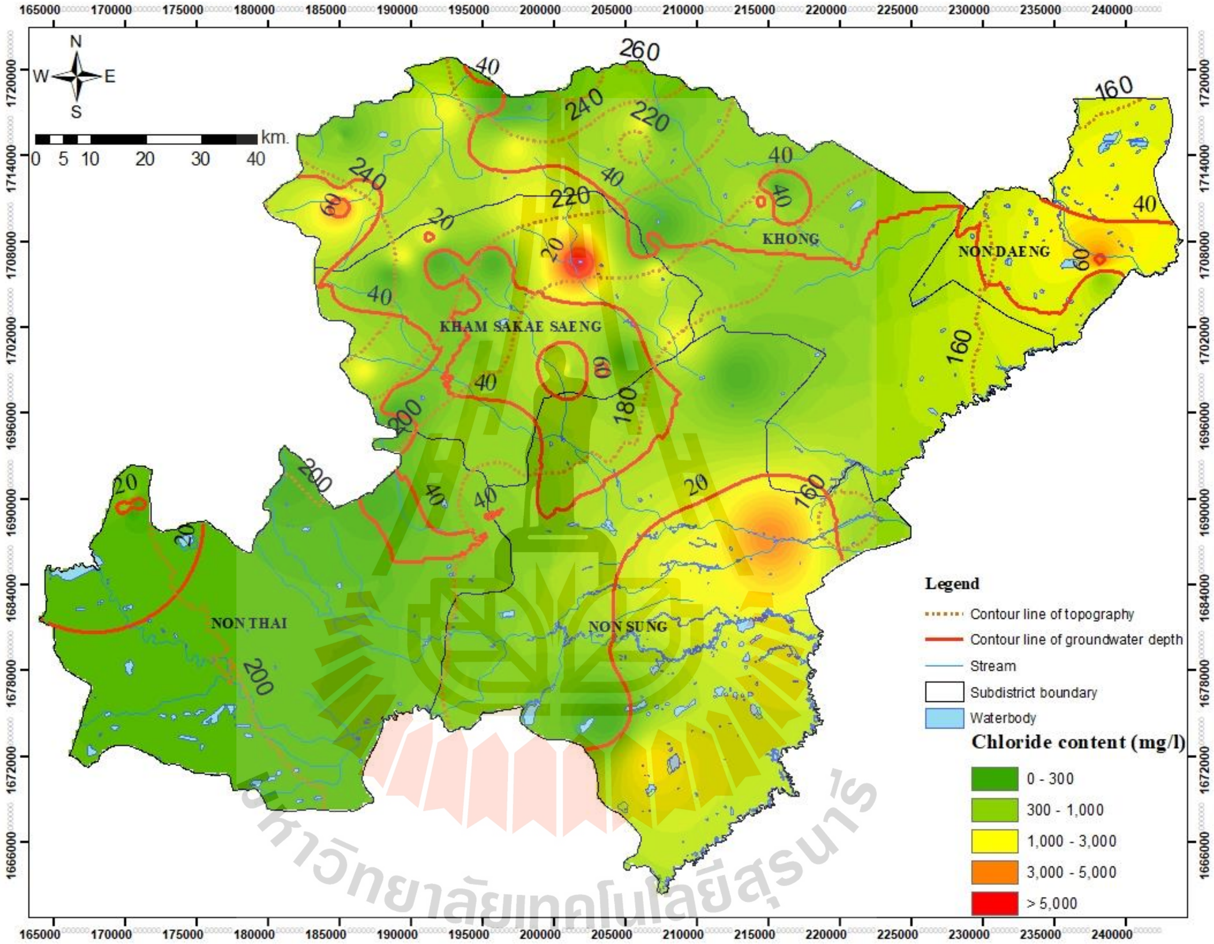


Figure 4.54 Map of chloride contents in groundwater samples of rainy season.

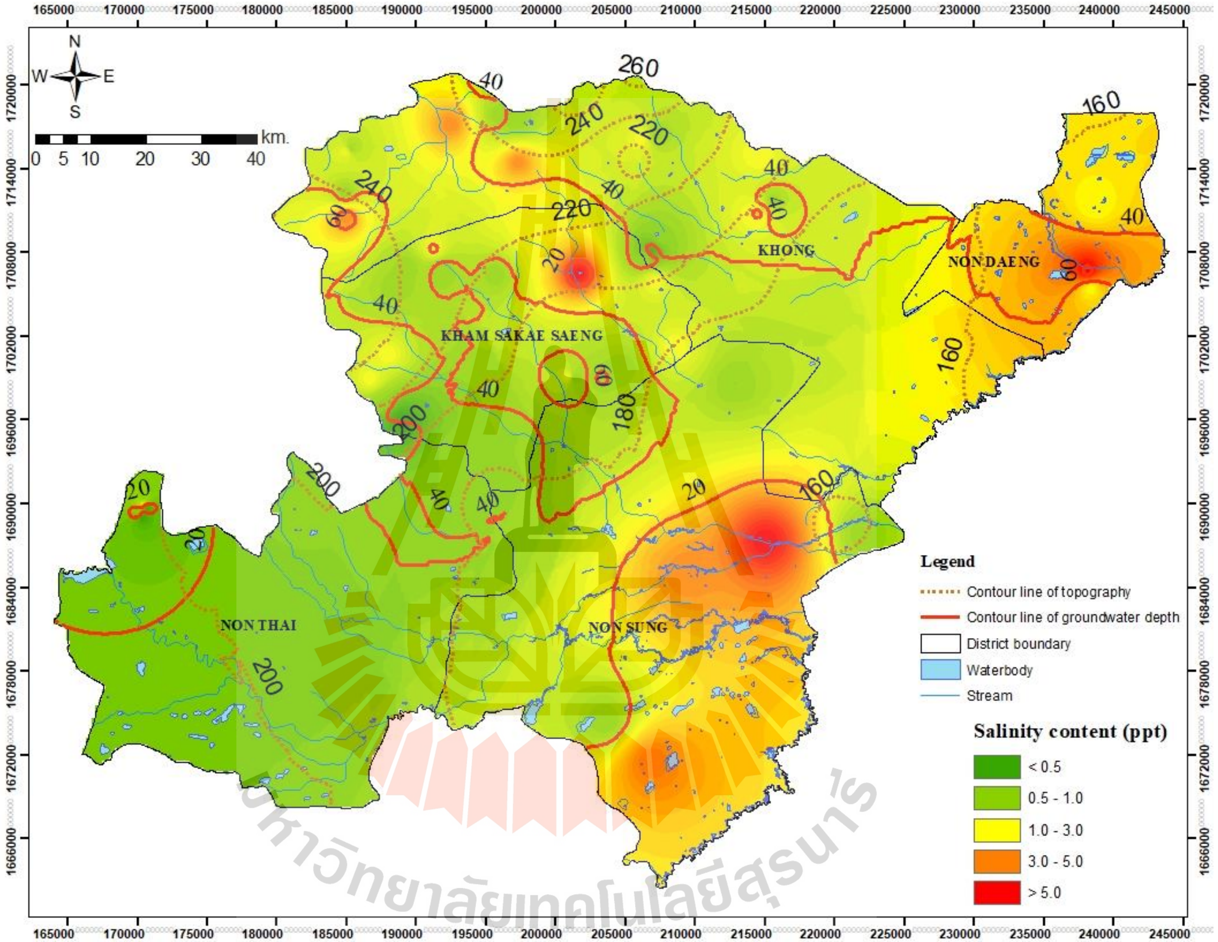


Figure 4.55 Map of salinity contents in groundwater samples of dry season.

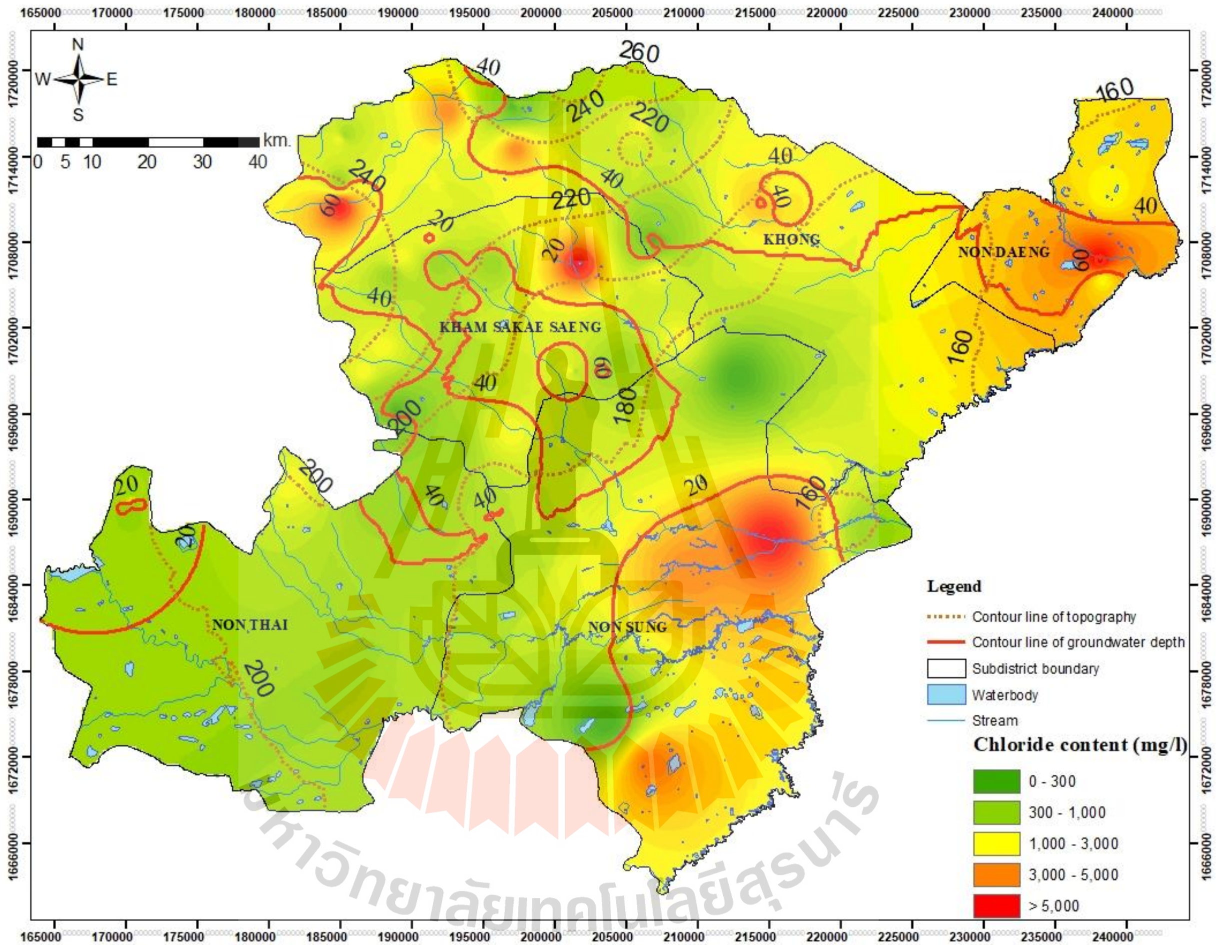


Figure 4.56 Map of chloride contents in groundwater samples of dry season.

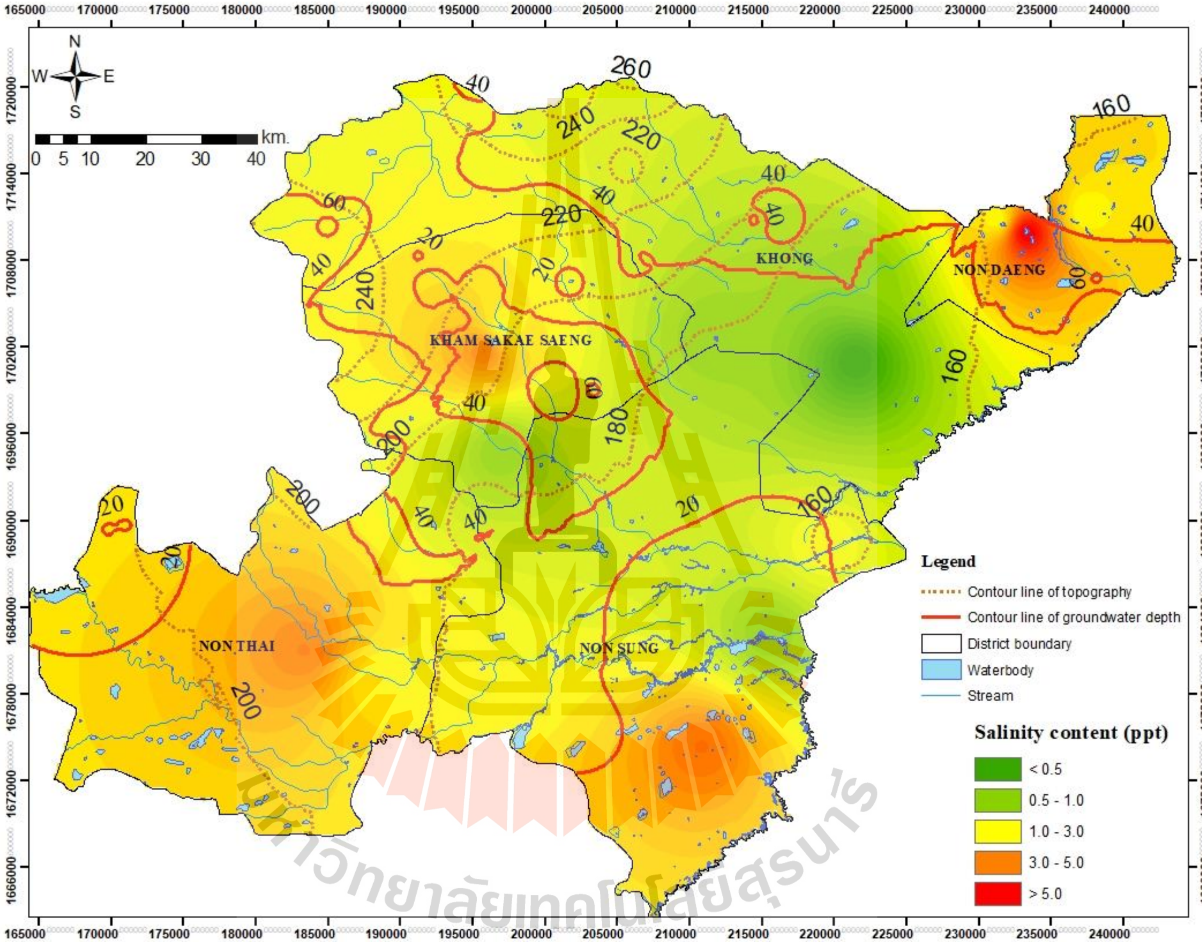


Figure 4.57 Map of salinity contents in surface water samples of rainy season.

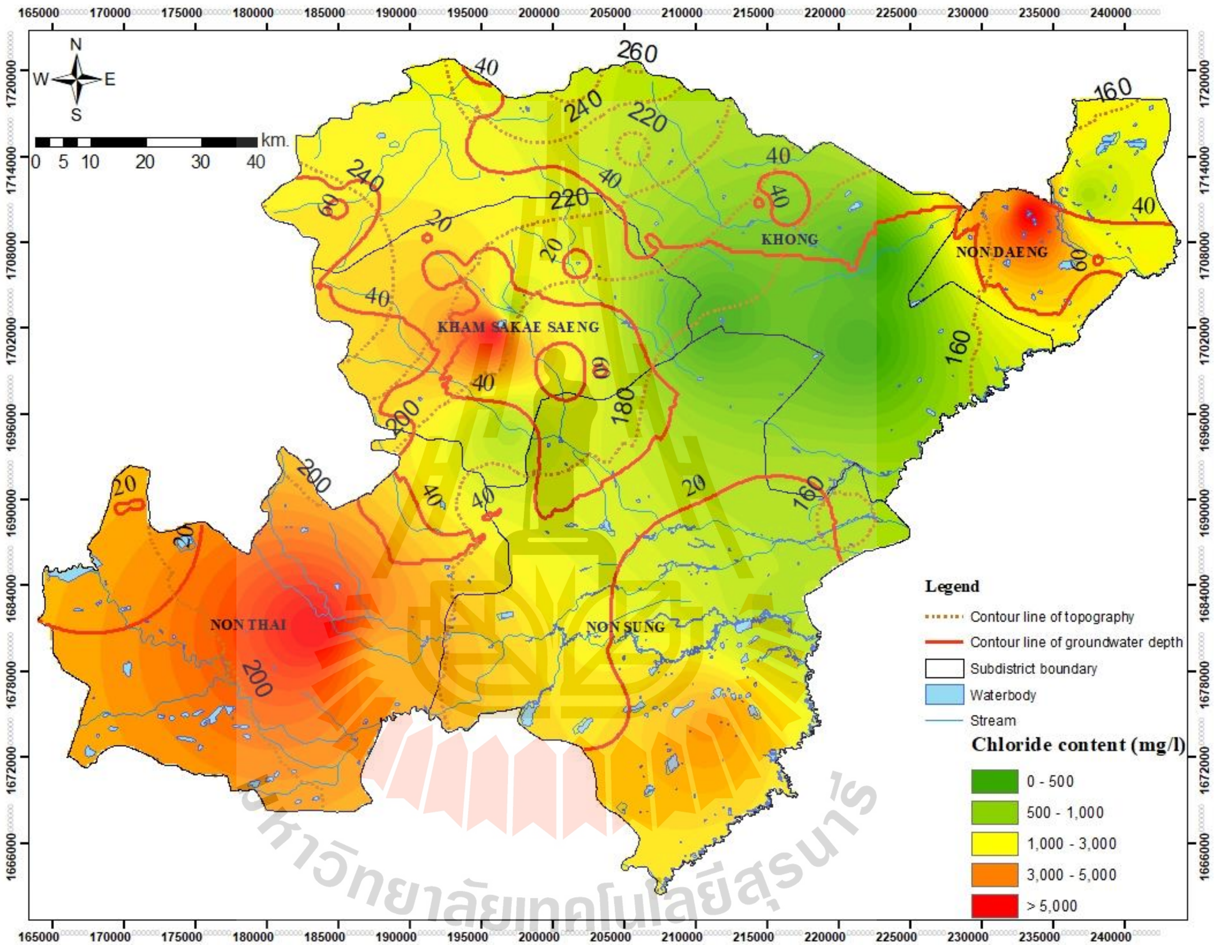


Figure 4.58 Map of chloride contents in surface water of rainy season.

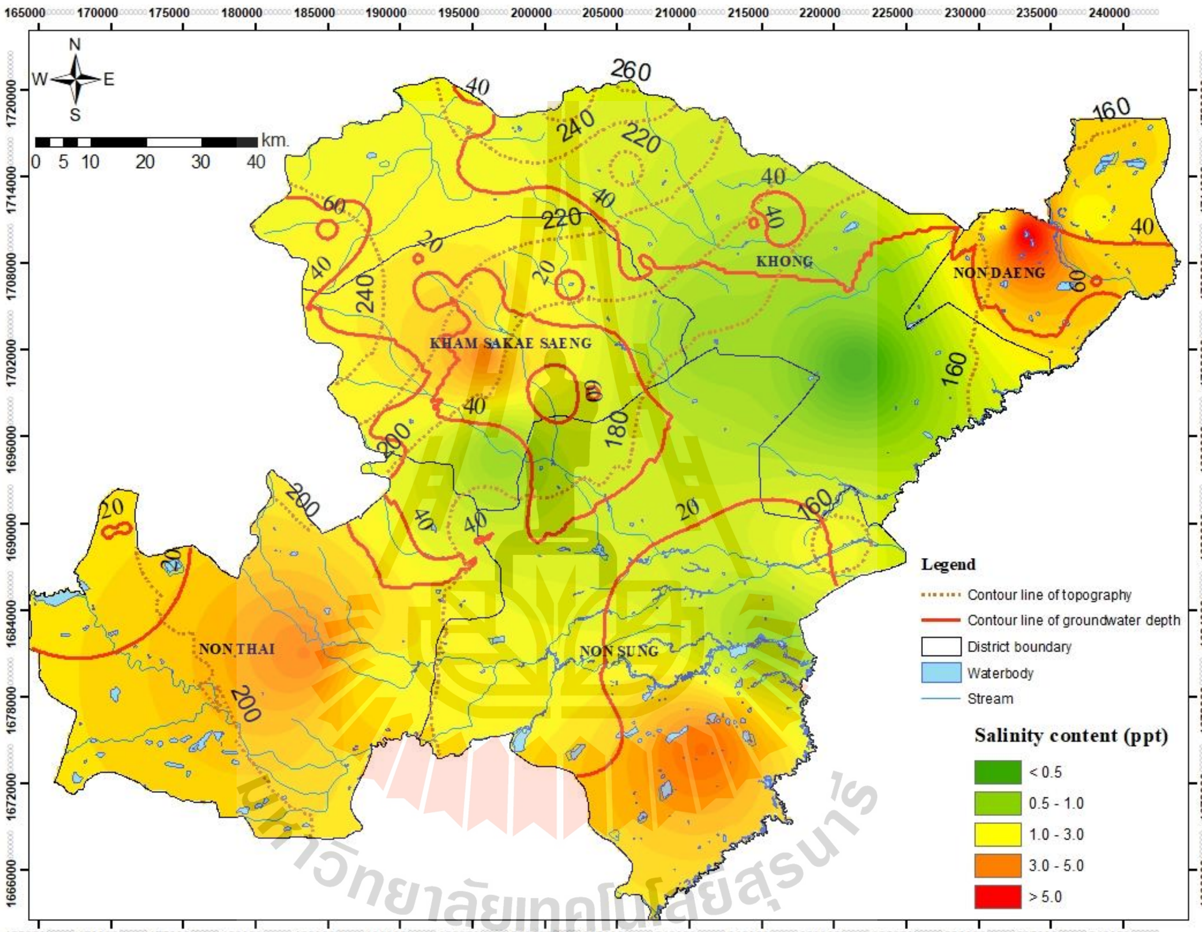


Figure 4.59 Map of salinity contents in surface water samples of dry season.

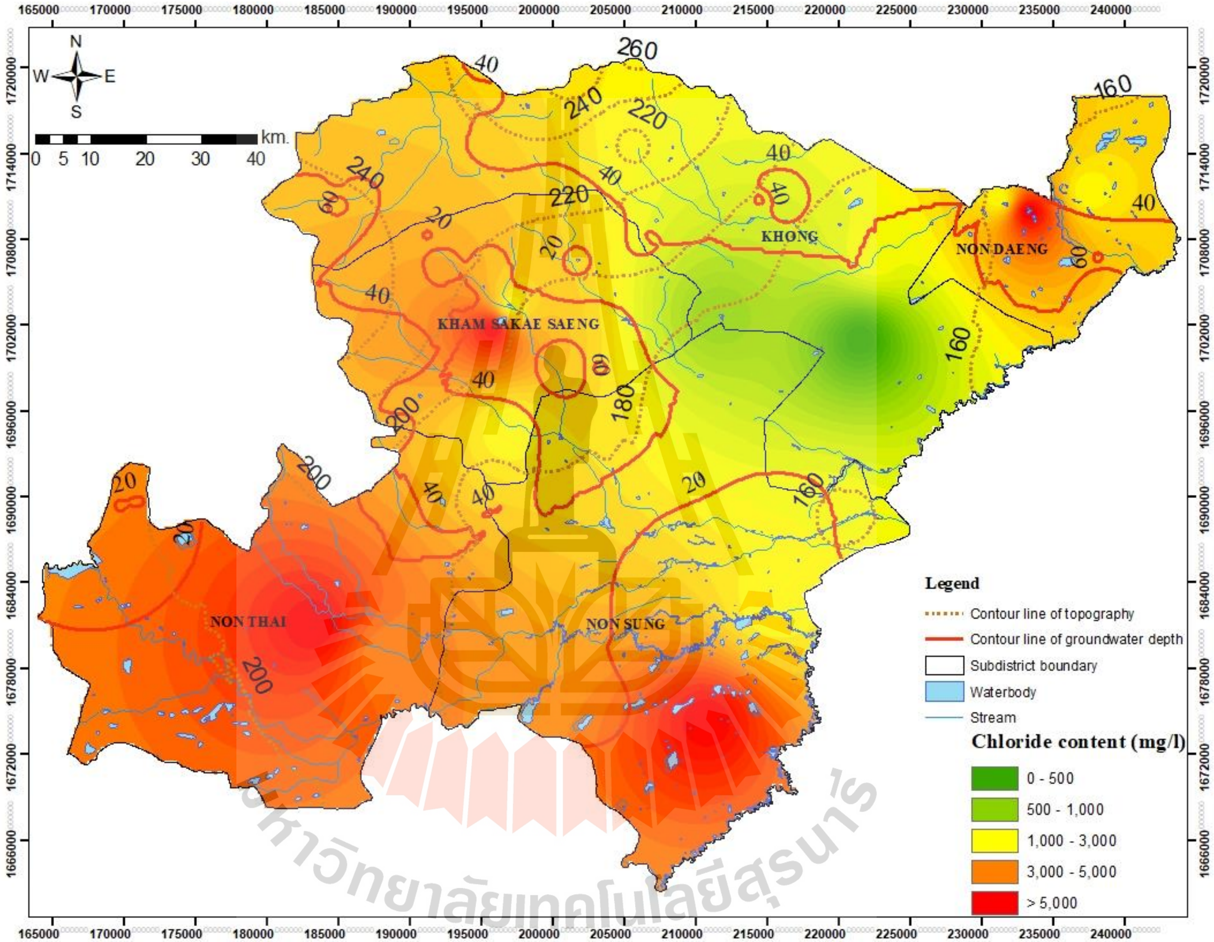


Figure 4.60 Map of chloride content surface water samples of dry season.

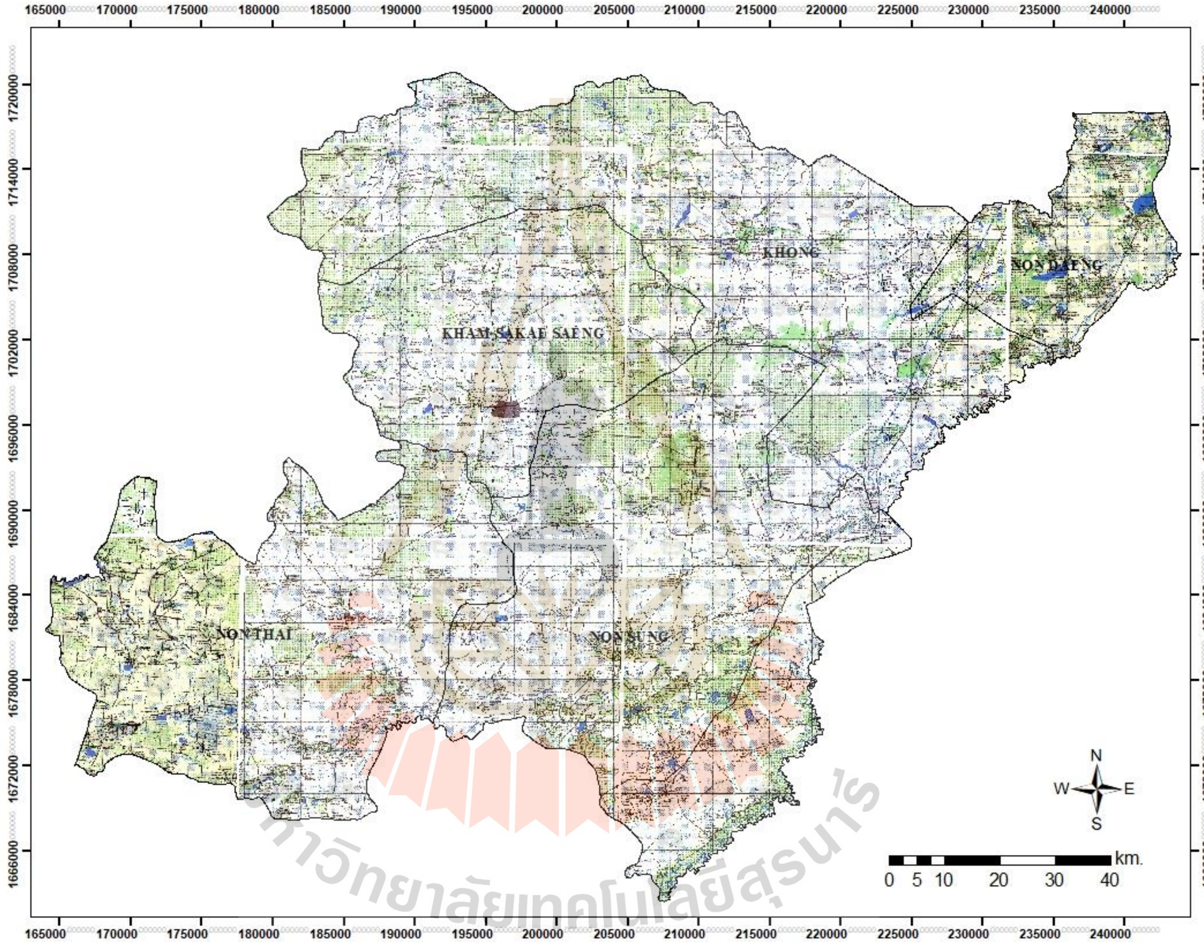


Figure 4.61 Topographic map of the study area.

4.7 Relationship between soil, groundwater, and surface water quality of the study area

Figures 4.49 to 4.60 exhibit distributions of salinity and chloride contents in soil, groundwater and surface water samples, taken in rainy season (October 2017) and dry season (May 2018). Distribution patterns of salinity contents coincide well with that of chloride contents in each sample type of both rainy season and dry season. The patterns of particular sample types of different season are similar, only concentrations in dry season are higher.

Distribution patterns of soil samples are similar with those of surface water samples. Notably, only difference occurs in Kham Sakae Saeng district, where pattern of high values appear in surface water samples but does not appear in soil samples. This is because, topography within Kham Sakae Saeng district is considerably high with altitude higher than 170 m. Therefore, leaching of salt and chloride from surface soil prevails. Finally, leaching processes end at surface water bodies where soluble salts are accumulated.

Distribution patterns of salinity and chloride contents in groundwater samples are less extent comparing to soil and surface water samples. However, they are more similar to the patterns of surface water. This can be described as inter-action beteen groundwater and rock salt occurs locally.

In conclusion, saline samples were related to the low-lying topography (MSL less than 170 m), i.e. Non Sung, southern part of Khong and Non Daeng, dry areas, and exposures of rock-salt. The high contents of salinity and chloride, related to the low-topography, indicate groundwater flow causing accumulation of saline water in the low attitude. Groundwater level must also be near soil surface (Wannakomol, 2005 and 2012). In rainy season, groundwater is qualified as fresh water, while it turns to be brackish and saline water in dry season. The saline soil area is easy to be observed by crystallization of salt on topsoil. Erosion and weathering of soluble salt from source rocks and subsequent transportation usually occur in rainy season. A part of salt solution infiltrates down to groundwater and another part flow along surface and later accumulate in streams and other water bodies. Amount of infiltration and surface flow varies upon amount of precipitation and water saturation of surface soil. In dry season, evaporation causes shallow saline groundwater rising to the surface, making higher salinity and chloride contents in soil and surface water.

Chemical contents in soil, groundwater and surface water were compared between rainy season and dry season. Summarization of the comparison was shown in Tables 4.5 to 4.8. It is evident that all contents of samples, taking in dry season are higher than in rainy season.

In Table 4.5, salinity in soil samples ranges from non saline to high saline in rainy season, while it ranges from non saline to extreme saline in dry season. In Table 4.7, salinity in groundwater samples ranges from non saline to high saline with majority of non saline in rainy season, while it ranges from non saline to extreme saline with more slight saline in dry season. In Table 4.9, salinity in surface water samples are mostly non saline in both seasons.

Table 4.5 Summarized comparison of physical and chemical components in soil samples according to different seasons.

District	Sub district	Location	MSL	pH		TDS		EC		Class		Salinity		Cl		XRD	XRF
				R	D	R	D	R	D	R	D	R	D	R	D		
Non Daeng	Don Yao Yai	Ban Don Yao Yai	155	7.48	8.97	1,338	8,754	2,676	17,508	SS	ES	1.97	14.60	1,791,439.89	4,000,671.41	Qtz = 86.03 Mus =5.23 Kao = 2.64 Cal =1.18 Hal = 0.26 Syl = 0.07 Gyp = 0.31 Anh = 0.03 Mag = 0.25 He = 0.06	SiO_2 = 64.20 Na_2O = 0.07 Al_2O_3 = 0.30 P_2O_5 = 0.62 SO_3 = 0.30 Cl = 3.72 K_2O = 1.80 CaO = 7.28 TiO_2 = 6.810 Fe_2O_3 = 13.05
	Don Yao Yai	Ban Don Yao Yai Health Promoting Hospital	155	7.12	9.01	7,768	-	15,536	-	HS	ES	9.57	44.50	8,836,926.09	12,223,570.40		
	Don Yao Yai	Ban Ra Han Kai	149	6.80	8.25	5,287	-	10,574	-	HS	ES	4.88	31.27	3,127,107.08	5,907,282.91		
	Don Yao Yai	Ban Pa Ta Bang	154	6.68	8.44	4,962	-	9,924	-	HS	ES	15.56	39.59	5,963,026.06	7,328,464.51		
	Samphaniang	Ban Samphaniang Mai	152	7.02	9.17	2,220	-	4,440	-	MS	ES	16.19	66.10	6,962,354.65	13,584,558.30		
	Samphaniang	Ban Na Khu Temple	155	7.04	9.11	59	627	118	1,254	NS	NS	0.55	1.62	253,207.05	1,050,809.26		
	Samphaniang	Ban Hua Talad	154	7.48	8.13	5,676	-	11,352	-	HS	ES	14.05	40.02	4,532,406.22	8,432,137.50		
	Samphaniang	Ban Fang School	152	7.30	8.68	6,580	9,151	13,160	18,302	HS	ES	15.07	30.20	5,159,093.67	7,077,137.08		
	Wang Hin	Ban Toie	153	6.98	8.72	514	2,772	1,028	5,544	NS	MS	0.72	4.50	12,660.35	2,025,656.41		
	Wang Hin	Ban Toie Temple	153	6.91	9.49	3,559	4,970	7,118	9,940	MS	HS	5.63	20.90	1,727,970.27	7,672,173.65		
	Wang Hin	Ban Hin Tang	152	6.87	9.16	3,648	5,948	7,296	11,896	MS	HS	0.88	6.72	670,998.69	3,823,426.47		
	Non Ta Then	Ban Non Ta Then	153	7.08	9.10	1,358	7,444	2,716	14,888	SS	HS	1.68	1.80	1,139,431.73	1,709,147.60		
	Non Ta Then	Ban Non Ta Then Temple	161	7.28	9.25	1,164	1,440	2,328	2,880	SS	SS	0.23	4.53	107,613.00	3,848,747.18		
	Non Ta Then	Ban Non Noi	154	6.55	8.90	1,880	6,771	3,760	13,542	SS	HS	3.80	5.13	1,892,722.71	3,962,690.35		
Non Thai	Dan Chak	Ban Dan Chak	175	7.33	9.11	1,082	8,377	2,164	16,754	SS	ES	4.09	10.20	2,139,599.58	3,342,333.08	Qtz = 79.81 Mus = 6.23 Kao = 2.01 Cal = 2.81 Hal = 0.24 Syl = 0.04 Gyp = 0.16 Mag = 0.31 He = 0.06	SiO_2 = 63.74 Na_2O = 0.02 MgO = 0.012 Al_2O_3 = 0.73 P_2O_5 = 0.70 SO_3 = 0.22 Cl = 3.01 K_2O = 1.60 CaO = 12.78 TiO_2 = 3.97 Fe_2O_3 = 11.53
	Dan Chak	Ban Dan Chak Temple	174	6.78	8.72	6,560	8,109	13,120	16,218	HS	ES	1.41	41.30	1,386,308.61	12,109,627.22		
	Non Thai	Sai Mit Non Thai School	178	6.86	9.05	3,855	-	7,710	-	MS	ES	15.41	23.83	5,317,348.08	7,957,031.58		
	Sam Rong	Ban Song Tham	180	7.58	9.20	724	8,287	1,448	16,574	NS	ES	0.73	10.40	165,597.41	4,772,952.92		
	Sam Rong	Ban Nong Krad	177	7.27	9.17	5,558	9,050	11,116	18,100	HS	ES	9.59	19.90	4,025,992.11	7,950,701.41		

Remark: Qtz = Quartz, Mus = Muscovite, Kao = Kaolinite, Cal = Calcite, Hal = Halite, Syl = Sylvite, Gyp = Gypsum, An = Anhydrite, Mag = Magnetite, and He = Hematite

R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.5 Summarized comparison of physical and chemical components in soil samples according to different seasons (continued).

District	Sub district	Location	MSL	pH		TDS		EC		Class		Salinity		Cl		XRD	XRF
				R	D	R	D	R	D	R	D	R	D	R	D		
vNon Sung	Mai	Ban Jan Dum 1	162	6.82	8.86	2,080	4,780	4,160	9,560	MS	HS	2.25	16.78	405,131.28	6,672,005.80	Qtz = 86.21 Mus = 5.13 Kao = 3.10 Cal = 0.61 Hal = 0.35 Syl = 0.08 Gyp = 0.39 Mag = 0.17 Hem = 0.03	SiO_2 = 61.327 Na_2O = 0.021 MgO = 0.033 Al_2O_3 = 1.354 P_2O_5 = 0.875 SO_3 = 0.209 Cl = 4.544 K_2O = 1.319 CaO = 11.948 TiO_2 = 3.501 Fe_2O_3 = 13.107
	Mai	Ban Jan Dum 2	161	6.76	9.14	723	2,558	1,446	5,116	NS	MS	0.73	3.07	101,282.82	2,000,335.70		
	Lum Khao	Ban Chad	161	6.83	9.05	2,710	9,946	5,420	19,892	MS	ES	14.64	29.50	4,671,670.10	5,532,574.07		
	Bing	Ban Bing	160	6.68	9.20	3,758	-	7,515	-	MS	ES	14.05	60.23	4,621,028.68	12,622,371.50		
	Bing	Ban Pet	166	7.40	8.56	4,922	-	9,844	-	HS	ES	15.95	26.40	5,817,432.00	6,760,628.27		
	Than Prasat	Ban Mai Kasem	153	6.08	8.91	5,619	6,617	11,238	13,234	HS	HS	5.45	14.00	1,569,883.72	4,038,652.47		
	Don Chomphu	Ban Som	163	7.05	8.37	3,961	9,642	7,922	19,284	MS	ES	12.90	14.90	3,519,578.01	4,589,377.80		
	Don Chomphu	Ban Don Chomphu	162	6.36	8.99	2,351	9,516	4,702	19,032	MS	ES	14.90	23.70	4,570,387.27	7,380,985.54		
	Don Chomphu	Ban Plo Pla	164	6.52	8.42	2,518	4,756	5,036	9,511	MS	HS	4.08	14.46	3,044,814.79	3,962,690.35		
Khong	Thephalai	Thephalai School	153	6.69	9.11	5,619	-	11,238	-	HS	ES	6.09	32.81	4,519,745.86	6,103,484.71	Qtz = 84.02 Mus = 5.22 Kao = 2.86 Cal = 1.86 Hal = 0.26 Syl = 0.06 Gyp = 0.36 An = 0.09 Mag = 0.21 He = 0.06	SiO_2 = 70.061 Na_2O = 0.056 MgO = 0.044 Al_2O_3 = 1.698 P_2O_5 = 0.519 SO_3 = 0.316 Cl = 2.425 K_2O = 1.041 CaO = 8.714 TiO_2 = 2.053 Fe_2O_3 = 11.998
	Thephalai	Ban Wat	154	6.62	8.71	2,856	9,256	5,712	18,512	MS	ES	4.10	28.00	3,206,234.29	5,038,820.32		
	Kham Sombun	Ban Kham School	156	6.43	9.20	3,214	9,792	6,428	19,584	MS	ES	4.09	22.50	2,635,885.40	4,671,670.10		
	Ta Chan	Ban Ta Chan	157	6.57	9.36	106	920	212	1,840	NS	NS	0.09	0.95	1,061,439.71	278,527.76		
	Khu Khat	Wat Koo Sa Mak Kee School	165	6.63	8.14	4,196	9,727	8,392	19,453	HS	ES	5.04	15.41	5,557,894.77	6,469,324.12		
	Khu Khat	Ban Ngiow	160	6.65	8.34	2,605	2,827	5,210	5,654	MS	MS	1.96	3.12	1,975,015.00	3,159,387.40		
	Khu Khat	Ban Pho Bit	161	6.43	9.35	3,880	8,377	7,760	16,754	MS	ES	4.89	16.90	7,760,796.12	3,930,955.54		
	Mueang Khong	Ban Don Yai	170	6.31	9.14	278	7,209	556	14,418	NS	HS	0.27	10.80	1,286,224.68	2,164,920.29		
	Mueang Khong	Ban Nong Khaem	177	6.30	9.11	5,064	-	10,128	-	HS	ES	4.49	48.40	4,747,632.21	10,584,054.74		
	Mueang Khong	Ban Non Wat	178	6.37	8.71	7,152	9,256	14,304	18,512	HS	ES	4.40	15.80	4,646,349.39	5,038,820.32		
	Ban Prang	Wat Pa Prang Thong	205	6.05	9.12	4,271	5,449	8,541	10,898	HS	HS	4.42	16.12	4,488,094.98	5,732,188.04		
	Nong Bua	Ban Ta Kim	197	6.00	9.15	819	2,271	1,638	4,542	NS	MS	0.85	3.00	985,962.12	3,824,059.49		

Remark: Qtz = Quartz, Mus = Muscovite, Kao = Kaolinite, Cal = Calcite, Hal = Halite, Syl = Sylvite, Gyp = Gypsum, An = Anhydrite, Mag = Magnetite, and He = Hematite

R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.5 Summarized comparison of physical and chemical components in soil samples according to different seasons (continued).

District	Sub district	Location	MSL	pH		TDS		EC		Class		Salinity		Cl		XRD	XRF
				R	D	R	D	R	D	R	D	R	D	R	D		
Kham Sakae Saeng	Mueang Kaset	Ban Rim Bung	190.1	6.67	6.79	113	1,052	226	2,104	NS	SS	0.10	0.51	1,050,809.26	1,386,308.61	Qtz = 87.44 Mus = 4.86 Kao =2.85 Cal = 0.01 Hal = 0.15 Syl = 0.09 Gyp = 0.49 An = 0.03 Mag = 0.17 He = 0.04	SiO_2 = 77.860 Na2O 0.055 MgO 0.064 Al_2O3 = 2.138 P_2O_5 = 1.092 SO_3 = 1.323 Cl = 2.077 K_2O = 2.338 CaO = 6.990 TiO_2 = 1.712 Fe_2O_3 = 4.062
	Nong Hua Fan	Ban Nong Hua Fan 1	186.3	6.35	6.67	3,717	5,356	7,434	10,712	MS	HS	2.82	14.46	2,911,881.09	9,216,736.66		
	Nong Hua Fan	Ban Nong Hua Fan 2	187	6.26	6.55	3,190	4,718	6,380	9,436	MS	HS	4.15	5.74	4,177,916.35	5,532,574.07		
	Nong Hua Fan	Ban Non Ban Na	200.8	6.63	6.84	128	1,290	256	2,580	NS	SS	0.13	1.01	1,114,111.03	1,709,147.41		
	Chiwuek	Chiwuek Temple	192.4	6.64	6.72	829	5,153	1,658	10,306	NS	HS	0.86	1.23	215,225.99	745,061.48		
	Kham Sakae Saeng	Ban Nong Jan School	186	6.46	6.14	2,918	3,020	5,836	6,040	MS	MS	2.43	4.03	2,373,816.11	4,025,992.11		
	Kham Sakae Saeng	Ban Non Jang	194	6.28	6.91	1,687	2,947	3,374	5,894	SS	MS	1.65	3.94	2,253,542.76	3,962,690.35		
	Mueang Nat	Ban Sema	173.6	6.35	6.76	482	1,534	964	3,068	NS	SS	0.50	0.87	1,310,346.49	1,892,722.71		
	Mueang Nat	Mueang Nat Temple	187.6	6.32	6.53	1,240	2,813	2,480	5,626	SS	MS	1.39	2.56	1,493,921.60	2,677,920.74		
	Mueang Nat	Ban Mueang Nat	177.2	6.39	6.48	93	502	186	1,004	NS	NS	0.08	0.72	1,057,139.44	1,569,883.72		

Remark: Qtz = Quartz, Mus = Muscovite, Kao = Kaolinite, Cal = Calcite, Hal = Halite, Syl = Sylvite, Gyp = Gypsum, An = Anhydrite, Mag = Magnetite, and He = Hematite

R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.6 Summarized comparison of cations in soil samples according to different seasons.

District	Sub district	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
			Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Don Yao Yai	Ban Don Yao Yai	591.00	812.70	97.50	148.70	31.74	32.61	0.369	2.300	957,600.00	1,099,200.00
	Don Yao Yai	Ban Don Yao Yai health promoting hospital	351.20	1,403.00	38.43	55.90	48.44	86.51	0.191	0.690	1,711,000.00	16,810,000.00
	Don Yao Yai	Ban Ra Han Kai	2,515.00	5,246.79	557.00	785.20	35.46	42.14	0.219	2.940	2,279,000.00	3,844,597.00
	Don Yao Yai	Ban Pa Ta Bang	742.70	1,019.09	214.50	446.10	45.16	67.98	0.183	2.220	7,814,000.00	8,790,044.00
	Samphaniang	Ban Samphaniang Mai	130.40	877.50	16.40	60.25	32.34	44.62	0.176	2.600	1,244,000.00	2,347,000.00
	Samphaniang	Ban Na Khu temple	140.70	150.05	15.54	15.70	19.92	34.34	0.290	0.326	101.55	478,800.00
	Samphaniang	Ban Hua Talad	152.13	235.70	626.00	792.45	49.76	55.42	1.920	2.010	5,021,790.18	5,543,872.00
	Samphaniang	Ban Fang school	1,791.50	2,577.00	453.50	865.00	30.29	47.48	0.168	2.600	8,350,092.31	8,926,543.00
	Wang Hin	Ban Toie	155.30	763.80	22.30	78.80	28.46	35.40	2.400	2.520	196.67	1,189,314.69
	Wang Hin	Ban Toie temple	384.25	1,903.00	48.80	1,106.00	220.30	289.70	2.879	3.900	2,294.33	9,003,314.69
	Wang Hin	Ban Hin Tang	305.80	681.20	51.60	168.60	33.71	41.46	0.257	0.323	1,658.33	3,638,040.18
	Non Ta Then	Ban Non Ta Then	100.40	975.00	56.40	274.40	10.22	26.49	0.454	0.512	4,521.00	536,092.31
	Non Ta Then	Ban Non Ta Then temple	1,761.00	121.56	3.98	174.33	54.60	95.06	1.251	0.216	341.90	3,687,459.82
	Non Ta Then	Ban Non Noi	1,103.00	389.60	54.80	103.00	17.26	35.30	0.124	0.219	4,306.00	3,909,848.21
Non Thai	Dan Chak	Ban Dan Chak	225.30	397.55	52.70	96.60	19.90	27.90	0.493	0.500	681,400.00	1,200,314.69
	Dan Chak	Ban Dan Chak temple	134.34	769.90	71.90	2,085.00	13.45	154.85	0.334	0.379	3,603.00	14,126,104.87
	Non Thai	Sai Mit Non Thai school	950.00	1,227.00	688.00	789.00	48.48	58.10	0.252	0.275	1,476,000.00	7,810,000.00
	Sam Rong	Ban Song Tham	72.35	1,350.50	25.10	462.00	13.00	23.82	0.250	0.280	549.00	5,122,790.18
	Sam Rong	Ban Nong Krad	113.28	1,082.00	223.00	1,154.00	28.34	80.45	0.389	0.437	754,600.00	9,143,314.69
Non Sung	Mai	Ban Jan Dum 1	251.90	1,040.00	37.30	276.50	12.62	64.72	0.251	0.308	763.20	8,020,092.31
	Mai	Ban Jan Dum 2	154.40	1,872.00	57.90	495.00	19.14	33.36	0.061	0.459	1,251,000.00	2,562,036.00
	Lum Khao	Ban Chad	402.75	1,866.50	65.20	277.00	23.11	25.43	0.145	0.283	1,008,000.00	5,064,000.00
	Bing	Ban Bing	1,373.50	1,881.00	233.00	408.00	13.26	13.43	1.088	1.470	2,683,500.00	5,051,790.18
	Bing	Ban Pet	251.40	6,086.00	169.50	412.00	30.58	32.60	0.200	0.368	863,500.00	7,534,000.00
	Than Prasat	Ban Mai Kasem	952.50	2,714.00	128.67	439.00	26.99	41.86	0.082	0.345	3,503,059.00	4,019,848.21
	Don Chomphu	Ban Som	346.40	434.95	57.30	551.00	22.62	25.51	0.098	0.325	1,051,500.00	2,927,000.00
	Don Chomphu	Ban Don Chomphu	54.68	339.40	10.10	71.10	11.56	17.77	0.315	0.421	1,019,500.00	5,022,350.18
	Don Chomphu	Ban Plo Pla	443.00	503.00	69.70	99.10	11.90	30.96	0.176	0.245	1,559,000.00	2,125,000.00

Remark: Unit of Calcium, Magnesium, Potassium, Iron, and Sodium = mg/l.

Table 4.6 Summarized comparison of cations in soil samples according to different seasons (continued).

District	Sub district	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
			Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Khong	Thephalai	Thephalai school	158.94	616.00	8.82	10.40	16.64	19.86	0.036	0.263	1,066.00	5,020,980.18
	Thephalai	Ban Wat	236.80	1,607.00	68.10	151.50	11.85	21.14	0.012	0.507	1,145,500.00	2,279,000.00
	Kham Sombun	Ban Kham school	629.00	826.50	184.80	200.00	36.95	42.40	0.134	0.319	1,064,000.00	1,980,000.00
	Ta Chan	Ban Ta Chan	79.89	171.38	7.73	22.15	4.52	5.12	0.449	0.790	303.50	480,800.00
	Khu Khat	Wat Koo Sa Mak Kee school	59.39	67.62	37.05	54.79	103.74	110.50	0.210	0.330	5,874,451.00	7,947,000.00
	Khu Khat	Ban Ngiow	273.80	562.81	79.60	82.34	22.58	30.77	0.044	0.156	893,471.00	1,252,000.00
	Khu Khat	Ban Pho Bit	665.00	3,604.50	44.20	346.00	13.90	42.32	0.310	0.530	596,000.00	9,004,000.00
	Mueang Khong	Ban Don Yai	525.60	1,341.50	78.25	226.40	43.11	118.38	0.047	0.239	3,648.00	474,000.00
	Mueang Khong	Ban Nong Khaem	908.50	1,147.00	522.00	619.00	77.53	110.64	0.012	0.592	2,553,000.00	5,071,000.00
	Mueang Khong	Ban Non Wat	1,156.00	1,621.00	342.00	585.00	52.36	69.52	0.031	0.315	768,000.00	5,051,790.18
	Ban Prang	Wat Pa Prang Thong	358.70	1,435.00	412.00	574.00	62.43	79.50	0.015	0.342	1,763,541.00	5,003,700.00
	Nong Bua	Ban Ta Kim	115.40	1,593.00	48.10	760.00	12.37	50.45	0.420	0.783	110.54	3,652,000.00
Kham Sakae Saeng	Mueang Kaset	Ban Rim Bung	536.40	614.33	138.50	168.53	25.39	48.55	0.069	0.098	847,000.00	1,435,189.00
	Nong Hua Fan	Ban Nong Hua Fan 1	160.78	210.86	27.17	108.09	7.24	12.62	0.087	0.096	480,000.00	654,723.00
	Nong Hua Fan	Ban Nong Hua Fan 2	452.67	561.47	718.00	752.17	21.29	35.98	0.073	0.089	857,600.00	1,021,359.00
	Nong Hua Fan	Ban Non Ban Na	310.10	1,640.00	92.20	795.00	21.02	61.69	0.304	0.560	1,561,000.00	2,110,000.00
	Chiwuek	Chiwuek temple	68.42	104.77	5.87	8.62	3.73	5.87	0.107	0.175	485,200.00	784,535.00
	Kham Sakae Saeng	Ban Nong Jan school	195.00	215.92	56.10	62.14	34.63	45.80	0.033	0.098	2,673,922.00	4,012,000.00
	Kham Sakae Saeng	Ban Non Jang	164.22	569.10	21.80	41.32	6.32	8.76	0.038	0.077	857,600.00	1,509,348.00
	Mueang Nat	Ban Sema	188.45	1,796.00	356.00	435.80	33.30	89.63	0.477	0.576	548,761.00	1,352,000.00
	Mueang Nat	Mueang Nat temple	121.40	989.40	174.33	377.10	77.20	114.89	0.432	0.544	519,342.00	1,372,000.00
	Mueang Nat	Ban Mueang Nat	25.31	914.10	18.30	176.00	14.33	263.00	0.295	0.354	212.70	8,550,000.00

Remark: Unit of Calcium, Magnesium, Potassium, Iron, and Sodium = mg/l.

Table 4.7 Summarized comparison of physical and chemical components in groundwater samples according to different seasons.

District	Sub district	Well no.	Location	MSL	pH		TDS		EC		Class		TH		Salinity		Cl	
					R	D	R	D	R	D	R	D	R	D	R	D	R	D
Non Daeng	Non Daeng	5705D031	Non Daeng Municipal School	156	7.58	7.89	1,934	7,614	3,794	15,288	SS	HS	339	1,600	2.02	22.70	3,499.57	51,046.54
	Non Daeng	5405B007	Phu Wittaya School	155	7.05	7.97	383	958	758	2,458	NS	SS	91	392	0.38	1.00	571.84	1,648.38
	Samphaniang	NR270	Ban Nong Ya Khao	157	7.61	7.80	917	1,010	1,830	2,020	NS	SS	313	360	0.90	1.07	1,587.46	2,202.90
Non Thai	Banlang	MG799	Ban Muang Kao School	192	7.89	7.48	456	1,074	912	2,138	NS	SS	172	241	0.44	1.08	276.50	1,002.00
	Banlang	-	Ban Muang Kao 1	202	7.60	7.92	532	902	1,064	1,804	NS	NS	278	292	0.56	0.87	312.96	872.00
	Banlang	-	Ban Muang Kao 2	198	7.29	7.94	468	487	940	970	NS	NS	306	350	0.48	0.89	176.23	894.00
	Banlang	-	Ban Muang Kao 3	195	7.61	7.63	590	812	1,180	1,632	NS	NS	256	278	0.58	0.84	518.06	972.32
	Banlang	SC409	Ban Muang Kao Temple	199	7.97	7.50	395	483	798	960	NS	NS	228	228	0.40	0.48	258.27	885.43
	Sai O	-	Ban Sawai	185	7.32	7.33	887	952	1,774	1,928	NS	NS	672	756	0.27	0.97	161.04	1,161.04
	Thanon Pho	PW13862	Ban Nong Ta Maen	197	7.47	7.41	511	607	1,022	1,214	NS	NS	241	256	0.59	0.71	543.89	899.21
	Makha	MG1571	Nong Doom Health Promoting Hospital	184	8.05	7.86	651	705	1,320	1,410	NS	NS	234	413	0.51	0.58	265.11	556.04
Non Sung	Lum Khao	-	Ban Dong Plong	163	7.71	7.42	1,980	14,400	3,960	28,800	MS	ES	1,560	3,400	2.09	7.54	3,760.00	7,540.00
	Lum Khao	-	Ban Krok Kham	158	7.32	7.21	784	3,074	1,608	6,148	NS	MS	332	3,044	0.85	3.76	2,303.17	3,548.00
	Than Prasat	-	Ban Talad Kae	154	7.26	7.67	963	1,064	1,926	2,128	NS	SS	250	414	0.59	1.03	312.57	964.00
	Dan Khla	-	Ban Bu	170	7.51	7.56	912	1,045	1,884	2,090	NS	SS	6	192	0.48	0.51	102.00	138.00
	Tanot	D0516	Ban Non Makok	165	7.78	7.24	3,044	6,720	6,088	13,440	MS	HS	166	730	1.50	2.70	1,701.32	3,912.00
	Phon Sungkhram	-	Ban Salao	169	7.32	7.12	405	995	810	1,970	NS	NS	198	513	0.49	0.96	157.00	203.00

Remark: R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.7 Summarized comparison of physical and chemical components in groundwater samples according to seasons (continued).

District	Sub district	Well no.	Location	MSL	pH		TDS		EC		Class		TH		Salinity		Cl	
					R	D	R	D	R	D	R	D	R	D	R	D	R	D
Khong	Non Teng	MY610	Ban Non Thong	198	7.43	7.48	456	467	896	936	NS	NS	18	230	0.43	0.45	17.85	103.31
	Non Teng	MY853	Ban Non Thong Temple	196	7.58	7.68	471	879	910	1,758	NS	NS	137	140	0.48	0.57	115.46	358.19
	Non Teng	PW16	Ban Nong Bua Gra Jai School	196	7.77	7.87	792	838	1,584	1,716	NS	NS	43	336	0.79	0.83	43.03	941.93
	Nong Manao	5805D004	Ban Don Klang School	208	7.36	7.83	159	247	318	494	NS	NS	22	91	0.16	0.25	21.79	358.54
	Nong Manao	5805A004	Ban Taluk Nam Khwang	217	7.50	7.50	1,030	1,746	2,060	3,492	SS	SS	304	328	1.09	1.98	1,060.43	2,958.42
	Nong Bua	MG679	Ban Nong Sakae School	212	7.61	7.74	402	867	804	1,732	NS	NS	43	416	0.09	0.86	42.86	948.01
	Nong Bua	AFD815	Ban Tha Yai 1	218	7.44	7.54	172	504	348	1,008	NS	NS	108	132	0.18	0.55	109.39	293.12
	Nong Bua	MY619	Ban Tha Yai 2	220	7.2	7.29	511	799	996	1,598	NS	NS	291	300	0.51	0.77	264.35	442.81
	Nong Bua	5505G052	Ban Ta Kim	197	7.19	7.44	1,487	2,006	2,890	4,012	SS	MS	379	425	1.46	3.3	2,260.63	3,942.48
	Nong Bua	25111	Ban Ba Dao Rueang	232	7.52	7.75	1,481	2,172	2,918	4,344	SS	MS	370	402	1.55	3.62	2,648.04	4,091.32
	Mueang Khong	5405B019	Ban Don Du	184	7.44	7.88	777	1,031	1,498	2,062	NS	SS	222	250	0.77	1.01	437.54	1,002.41
	Mueang Khong	MG1014	Ban Kok Pet 1	181	7.54	7.70	1,699	2,273	3,246	4,546	SS	MS	148	168	1.84	3.01	2,420.15	4,101.25
	Mueang Khong	MG832	Ban Kok Pet 2	178	7.63	7.98	632	921	1,260	1,842	NS	NS	79	102	0.65	0.91	464.89	1,049.26
	Mueang Khong	MY327	Ban Kok Pet Temple	183	7.52	7.76	602	997	1,208	1,994	NS	NS	220	243	0.63	0.98	288.66	1,101.94
	Ban Prang	PW20092	Ban Mai Don Tua Pap	226	7.8	7.99	920	1,784	1,880	3,568	NS	SS	132	151	0.91	2.05	805.2	2,168.53
	Ban Prang	MG1017	Ban Don Tua	223	7.65	7.82	849	869	1,690	1,744	NS	NS	41	298	0.08	0.85	41.08	741.39
	Ban Prang	AFD806	Ban Huay Luek	222	7.41	7.87	1,021	1,551	2,052	3,102	SS	SS	343	453	0.42	0.58	498.31	673.84
	Ban Prang	5905H052	Ban Thap Ma Kham School	225	7.73	7.97	2,459	3,404	4,918	6,808	MS	MS	234	348	1.8	3.12	3,542.68	6,117.99

Remark: R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.7 Summarized comparison of physical and chemical components in groundwater samples according to seasons (continued).

District	Sub district	Well no.	Location	MSL	pH		TDS		EC		Class		TH		Salinity		Cl	
					R	D	R	D	R	D	R	D	R	D	R	D	R	D
Kham Sakae Saeng	Non Mueang	5805B035	Ban Non Mueang School	207	6.94	7.51	515	835	1,046	1,670	NS	NS	295	530	0.51	0.53	215.73	1,095.37
	Non Mueang	SC1145	Ban Taluk Hin	221	6.64	7.43	490	517	1,020	1,034	NS	NS	156	265	0.24	0.55	227.89	414
	Non Mueang	MY331	Ban Ngio School	212	6.57	7.14	1,069	1,074	2,092	2,114	SS	SS	295	445	1.06	1.6	1,124.24	1,968.94
	Non Mueang	MY337	Ban Khum Muang	214	6.38	7	823	988	1,826	1,856	NS	NS	523	530	0.89	0.9	1,051.32	1,076.16
	Non Mueang	MG320	Ban Sa Kruat	206	6.55	7.44	568	716	1,080	1,576	NS	NS	279	329	0.53	0.56	258.27	683.66
	Mueang Kaset	5605B031	Ban Khu Mueang School	200	6.88	7.53	302	537	604	1,086	NS	NS	234	298	0.36	0.59	133.69	437.54
	Nong Hua Fan	5905D059	Chomchon Nong Hua Fan school	184	6.15	7.47	3,940	4,297	8,156	8,594	HS	HS	191	228	4.32	4.38	6,168.12	7,305.28
	Nong Hua Fan	MY228	Ban Non Makluea Temple	213	6.58	7.21	1,435	1,719	2,870	3,438	SS	SS	304	384	1.35	1.43	1,815.49	2,175.90
	Nong Hua Fan	5505C054	Ban Non Makluea School	212	6.85	7.34	1,247	1,487	2,248	2,890	SS	SS	314	334	1.36	1.48	1,952.23	2,311.79
	Nong Hua Fan	MG1637	Ban Jod School	198	6.43	7.66	1,166	1,998	2,286	3,996	SS	SS	654	733	1.28	1.45	1,739.53	2,310.77
	Chiwuek	5905H029	Chiwuek 1	199	6.68	7.08	368	480	738	960	NS	NS	67	156	0.36	0.49	240.04	358.54
	Chiwuek	5805H044	Chiwuek 2	207	6.13	6.85	995	1,247	1,989	2,248	NS	SS	314	414	0.93	1.39	832.54	2,060.40
	Chiwuek	PW73	Ban Hua Bung	200	6.48	6.64	137	490	284	1,020	NS	NS	116	191	0.07	0.24	45.58	227.9
	Chiwuek	MY458	Ban Nong Pho	207	6.5	6.57	637	1,069	1,278	2,092	NS	SS	329	399	0.64	0.81	525.66	948.01
	Chiwuek	5805H049	Ban Non Phak Chi School	209	6.18	6.19	1,150	1,487	2,228	2,890	SS	SS	87	133	1.19	1.43	1,450.88	2,217.99
	Kham Sakae Saeng	MG1441	Ban Nook 1	185	6.78	6.92	498	587	960	1,178	NS	NS	270	436	0.51	0.99	595.54	1,266.29
	Kham Sakae Saeng	MG1442	Ban Nook 2	182	6.08	6.13	480	2,050	960	4,002	NS	MS	156	234	0.49	0.88	376.77	805.2
	Kham Sakae Saeng	MG1443	Ban Nook School	182	6.78	7.19	1,082	1,602	2,160	3,204	SS	SS	384	406	1.15	1.31	1,190.33	1,777.51
	Kham Sakae Saeng	MG318	Ban Namab	184	6.52	7	537	600	1,086	1,200	NS	NS	300	322	0.29	0.59	443.62	734.55
	Kham Sakae Saeng	AFD998	Ban Bu La Kro	177	6.53	6.7	842	1,447	1,682	2,894	NS	SS	304	435	0.88	0.97	786.97	1,253.37
	Mueang Nat	5705B005	Ban Sema School	176	6.07	6.98	1,266	1,494	2,532	2,998	SS	SS	198	314	1.19	1.42	1,815.49	1,975.01
	Mueang Nat	AA1655	Ban Nong Pho Namab School	182	6.36	6.52	184	537	366	1,086	NS	NS	109	300	0.25	0.51	237	492.48

Remark: R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.8 Summarized comparison of cations in groundwater samples according to different seasons.

District	Sub district	Well no.	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
				Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Non Daeng	5705D031	Non Daeng Municipal school	102.00	708.00	37.90	169.80	11.66	102.48	0.13	0.56	576.20	2,039,000.00
	Non Daeng	5405B007	Phu Wittaya school	25.45	47.01	7.64	13.24	2.27	7.48	0.11	0.53	135.15	1,274.00
Non Thai	Banlang		Ban Muang Kao 2	6.09	7.42	9.18	10.24	4.38	5.68	0.63	0.71	278.30	354.98
	Makha	MG1571	Nong Doom health promoting hospital	11.83	28.84	7.36	26.98	3.79	5.16	0.20	0.30	234.90	744.30
Non Sung	Than Prasat	-	Ban Talad Kae	12.14	31.42	9.24	32.92	4.12	5.54	0.51	0.75	293.50	815.40
	Tanot	D0516	Ban Non Makok	28.62	35.24	8.01	8.43	3.56	4.19	0.10	0.52	422.00	581.00
Khong	Nong Bua	MG679	Ban Nong Sakae school	6.40	99.36	15.48	48.40	3.81	4.07	0.11	0.54	159.55	369.30
	Nong Bua	5505G052	Ban Ta Kim	123.80	134.90	26.12	41.40	12.05	12.88	9.76	9.79	389.80	765.20
Kham Sakae Saeng	Non Mueang	MY337	Ban Khum Muang	21.92	98.72	18.54	31.98	8.17	8.65	0.15	0.43	241.60	425.00
	Nong Hua Fan	MG1637	Ban Jod school	15.53	168.50	31.90	64.80	5.89	6.00	0.13	0.15	216.85	516.40

Remark: Unit of Calcium, Magnesium, Potassium, Iron, and Sodium = mg/l.

Table 4.9 Summarized comparison of physical and chemical properties in surface water samples according to different seasons.

District	Sub district	Location	MSL	pH		TDS		EC		Class		TH		Salinity		Cl	
				R	D	R	D	R	D	R	D	R	D	R	D	R	D
Non Daeng	Non Daeng	Non Ta Then reservoir	153	7.18	7.80	1,366	1,591	2,716	3,182	SS	MS	213	230	1.42	1.48	2,856.18	2,581.95
	Don Yao Yai	Don Yao Yai Health Promoting Hospital reservoir	155	7.63	7.89	4,838	5,956	9,676	11,912	HS	HS	81	143	2.41	7.54	4,430.11	20,281.88
	Samphaniang	Huai Fang	152	7.28	7.43	530	2,164	1,060	4,358	NS	MS	136	551	0.65	0.93	934.33	1,328.16
Non Thai	Dan Chak	Ban Dan Chak reservoir	174	7.21	7.35	1,392	1,467	2,774	2,870	SS	SS	279	283	1.45	2.32	2,582.71	3,671.25
	Non Thai	Don Bot Temple reservoir	175	7.47	7.54	2,448	2,533	4,860	5,066	MS	MS	307	794	2.71	3.19	5,052.24	6,897.36
Non Sung	Bing	Ban Bing reservoir	160	7.44	7.71	1,423	3,044	2,846	6,088	SS	MS	177	730	1.34	4.98	2,303.17	9,799.11
	Than Prasat	Lum Than Prasat River (Ban Mai Kasem Tai)	159	7.52	7.78	995	1,064	1,970	2,128	NS	SS	198	250	0.96	1.03	1,684.99	1,800.30
	Don Chomphu	Lum Chiang Krai River (Ban Som)	162	7.39	7.54	912	784	1,884	1,608	NS	NS	192	332	0.94	0.95	1,442.52	1,501.01
Khong	Khu Khat	Kud Vien reservoir	164	7.13	7.63	176	365	352	730	NS	NS	95	102	0.88	0.93	1,161.04	1,452.77
	Mueang Khong	Bueng Don Yai reservoir	177	7.83	7.96	494	496	984	992	NS	NS	188	296	0.05	0.55	42.49	695.81
	Kham Sombun	Non Si Fun reservoir	166	7.55	7.69	142	242	284	483	NS	NS	106	118	0.06	0.15	54.69	230.43
Kham Sakae Saeng	Kham Sakaesaeng	Ban Bu La Kro Reservoir	177	7.31	7.83	761	844	1,522	1,704	NS	NS	312	321	0.90	0.99	1,276.16	1,800.30
	Kham Sakaesaeng	Ban Yakha Non Jang School Reservoir	186	7.01	7.12	2,080	2,992	4,160	6,066	MS	MS	1,520	1,570	2.75	4.15	5,393.31	8,380.90
	Kham Sakaesaeng	Non Lan Canal	186	7.16	7.20	666	1,266	1,332	2,544	NS	SS	233	288	0.68	1.38	917.62	2,546.25

Remark: R = Rainy season, D = Dry season, NS = Non saline, SS = Slightly saline, MS = Moderate saline, HS = High saline, and ES = Extreme saline

Unit of EC = us/cm, TDS = mg/l, Salinity content = ppt, and Chloride content = mg/l.

Table 4.10 Summarized comparison of cations in surface water samples according to the season.

District	Sub district	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
			Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Non Daeng	Non Ta Then reservoir	76.34	101.70	14.52	23.12	7.03	7.15	0.22	0.43	539.60	1,049.50
	Don Yao Yai	Ban Don Yao Yai health promoting hospital	33.81	59.81	1.90	2.18	6.42	6.76	0.53	0.62	133.20	12,391.43
Non Thai	Dan Chak	Ban Dan Chak reservoir	82.80	86.08	5.50	24.06	6.67	8.01	0.23	0.40	488.60	1,033.00
	Non Thai	Don Bot temple reservoir	108.20	114.67	15.70	19.54	4.41	4.79	0.17	0.48	1,172.50	3,355.71
Non Sung	Bing	Bing reservoir	17.26	61.54	8.72	17.60	5.59	5.78	0.53	5.66	515.60	4,361.43
	Don Chomphu	Lum Chiang Krai river (Ban Som)	33.91	36.21	7.50	16.16	4.72	7.82	0.41	8.79	295.50	892.60
Khong	Khu Khat	Kud Vien reservoir	19.50	29.84	4.78	5.50	8.58	10.49	0.43	0.48	103.04	110.92
	Mueang Khong	Bueng Don Yai reservoir	31.81	34.83	11.20	14.78	6.52	7.48	0.22	0.30	141.50	249.80
	Kham Sombun	Non Si Fun reservoir	23.62	30.12	7.71	9.12	6.35	7.78	0.63	0.80	4.79	8.45
Kham Sakae Saeng	Kham Sakae Saeng	Ban Bu La Kro reservoir	75.38	84.60	17.32	27.54	14.16	15.22	0.17	0.37	244.50	472.40
	Kham Sakae Saeng	Ban Yakha Non Jang school reservoir	429.80	593.80	68.60	243.00	14.93	27.48	0.21	0.47	956.60	1,139.20
	Kham Sakae Saeng	Non Lan canal	25.51	40.97	16.36	24.80	2.14	3.15	0.07	1.16	522.20	549.60

Remark: Unit of Calcium, Magnesium, Potassium, Iron, and Sodium = mg/l.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

4.8 Conclusions

Analytical results showed that chemical contents of samples collected in dry season are higher than samples from rainy season. The relationship between salinity and chloride contents in soil, groundwater samples were displayed in distribution maps (Figure 4.49 to 4.52). The salinity and chloride contents were closely related in both rainy and dry season. The only difference that can be seen between rainy and dry season, is that the extent of distribution patterns in dry season is greater than in rainy season. This is because contents of particular parameter in the same sampling site are higher in dry season. However, values of rainy season samples are generally lower than values of dry season. The lower values were the effect of dilution by rain water. On the other hand, infilling of rain water can cause ascending of groundwater table in rainy season. Salinity and chloride contents in soil are higher than in groundwater and surface water. This phenomenon can be explained as when groundwater seeps out into ground surface, later evaporates and leaves residue of salt behind on soil surface in low elevation areas. The maps demonstrated that seasons, elevation of topography, and groundwater level are factors, controlling the values of chloride contents, and salinity contents. Low-lying (MSL less than 170 meters) areas, i.e. Non Sung, southern part of Khong and Non Daeng, shallow groundwater level areas are locations that transported saline groundwater seeps out and deposits salt on ground surface. Fracture zones are possible to be path way that saline groundwater rises up from depth. The crisis area of saline soil of both seasons in Non Daeng and Non Sung districts, was caused by lower topography and shallow groundwater level. In high-elevated area (MSL more than 170 m), groundwater level is too deep until saline groundwater cannot reach surface.

4.9 Recommendations

Scale of this study is rather regional scale of investigation. Bigger picture of the saline affected areas has been studied. More detailed scale of the study is recommended to proceed the findings in this study.

There is more saline soil affected areas in Nakhon Ratchasima province and other provinces in the Northeast. Similar studies in these areas are in both regional and detailed scale.

Behaviors of groundwater flow are other subjects of interesting, since it is one of major causes of salinity in sur face soil.

Salinity in soil, groundwater and surface water in different season of the year has been determined in this study. Study of consecutive years are also intrigued.

Studying salinity, specified in agricultural areas, is recommended. Results of such study may lead to solve long been problem of saline soil in the Northeast.

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APPENDIX A

CHEMICAL PROPERTIES DATA

Chemical properties data

Table A1 Chemical properties of soil samples according to different seasons.

District	Sub district	UTM E	UTM N	Location	pH		EC		TDS		Salinity content		Chloride content	
					Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Non Daeng	Don Yao Yai	232976	1709975	Ban Don Yao Yai	7.48	8.971	2,676	17,508	1,338	8,754	1.97	14.60	1,791,439.89	4,000,671.41
	Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	7.12	9.014	15,536	-	7,768	-	9.57	44.50	8,836,926.09	12,223,570.40
	Don Yao Yai	235888	1706652	Ban Ra Han Kai	6.8	8.25	10,574	-	5,287	-	4.88	31.27	3,127,107.08	5,907,282.91
	Don Yao Yai	231433	1707268	Ban Pa Ta Bang	6.68	8.44	9,924	-	4,962	-	15.56	39.59	5,963,026.06	7,328,464.51
	Samphaniang	240107	1711089	Ban Samphaniang Mai	7.02	9.17	4,440	-	2,220	-	16.19	66.10	6,962,354.65	13,584,558.30
	Samphaniang	235598	1712364	Ban Na Khu temple	7.04	9.11	118	1,254	59	627	0.55	1.62	253,207.05	1,050,809.26
	Samphaniang	235817	1711564	Ban Hua Talad	7.48	8.13	11,352	-	5,676	-	14.05	40.02	4,532,406.22	8,432,137.50
	Samphaniang	237465	1711266	Ban Fang school	7.30	8.68	13,160	18,302	6,580	9,151	15.07	30.20	5,159,093.67	7,077,137.08
	Wang Hin	235813	1712985	Ban Toie	6.98	8.723	1,028	5,544	514	2,772	0.72	4.50	12,660.35	2,025,656.41
	Wang Hin	236232	1714263	Ban Toie temple	6.91	9.493	7,118	9,940	3,559	4,970	5.63	20.90	1,727,970.27	7,672,173.65
	Wang Hin	239537	1713359	Ban Hin Tang	6.87	9.16	7,296	11,896	3,648	5,948	0.88	6.72	670,998.69	3,823,426.47
	Non Ta Then	231234	1710843	Ban Non Ta Then	7.08	9.10	2,716	14,888	1,358	7,444	1.68	1.80	1,139,431.73	1,709,147.60
	Non Ta Then	232310	1711124	Ban Non Ta Then temple	7.28	9.248	2,328	2,880	1,164	1,440	0.23	4.53	107,613.00	3,848,747.18
	Non Ta Then	228668	1709073	Ban Non Noi	6.55	8.90	3,760	13,542	1,880	6,771	3.80	5.13	1,892,722.71	3,962,690.35
Non Thai	Dan Chak	187902	1679575	Ban Dan Chak	7.33	9.107	2,164	16,754	1,082	8,377	4.09	10.20	2,139,599.58	3,342,333.08
	Dan Chak	188274	1678720	Ban Dan Chak temple	6.78	8.718	13,120	16,218	6,560	8,109	1.41	41.30	1,386,308.61	12,109,627.22
	Non Thai	184673	1682935	Sai Mit Non Thai school	6.86	9.053	7,710	-	3,855	-	15.41	23.83	5,317,348.08	7,957,031.58
	Sam Rong	178417	1673084	Ban Song Tham	7.58	9.20	1,448	16,574	724	8,287	0.73	10.40	165,597.41	4,772,952.92
	Sam Rong	178814	1671006	Ban Nong Krad	7.27	9.171	11,116	18,100	5,558	9,050	9.59	19.90	4,025,992.11	7,950,701.41
Non Sung	Mai	209858	1675501	Ban Jan Dum 1	6.82	8.862	4,160	9,560	2,080	4,780	2.25	16.78	405,131.28	6,672,005.80
	Mai	210482	1679135	Ban Jan Dum 2	6.756	9.142	1,446	5,116	723	2,558	0.73	3.07	101,282.82	2,000,335.70
	Lum Khao	210114	1680537	Ban Chad	6.83	9.047	5,420	19,584	2,710	9,946	14.64	29.50	4,671,670.10	5,532,574.07
	Bing	210826	1674312	Ban Bing	6.68	9.20	7,515	-	3,758	-	14.05	60.23	4,621,028.68	12,622,371.50
	Bing	213043	1674234	Ban Pet	7.40	8.56	9,844	-	4,922	-	15.95	26.40	5,817,432.00	6,760,628.27
	Than Prasat	218707	1677319	Ban Mai Kasem	6.08	8.91	11,238	13,234	5,619	6,617	5.45	14.00	1,569,883.72	4,038,652.47
	Don Chomphu	214228	1680448	Ban Som	7.052	8.37	7,922	19,284	3,961	9,642	12.9	14.90	3,519,578.01	4,589,377.80
	Don Chomphu	214406	1677123	Ban Don Chomphu	6.36	8.99	4,702	19,032	2,351	9,516	14.9	23.70	4,570,387.27	7,380,985.54
	Don Chomphu	214590	1678757	Ban Plo Pla	6.523	8.42	5,036	9,511	2,518	4,756	4.08	14.46	3,044,814.79	3,962,690.35

Table A1 Chemical properties of soil samples according to different seasons (continued).

District	Sub district	UTM E	UTM N	Location	pH		EC		TDS		Salinity content		Chloride content	
					Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Khong	Thephalai	228122	1702977	Thephalai school	6.69	9.11	11,238	-	5,619	-	6.09	32.81	4,519,745.86	6,103,484.71
	Thephalai	226707	1699278	Ban Wat	6.62	8.71	5,712	18,512	2,856	9,256	4.1	28	3,206,234.29	5,038,820.32
	Kham Sombun	222077	1700185	Ban Kham school	6.43	9.2	6,428	19,584	3,214	9,792	4.09	22.5	2,635,885.40	4,671,670.10
	Ta Chan	220572	1694233	Ban Ta Chan	6.57	9.36	212	1,840	106	920	0.09	0.95	1,061,439.71	278,527.76
	Khu Khat	222455	1706779	Wat Koo Sa Mak Kee school	6.63	8.14	8,392	19,453	4,196	9,727	5.04	15.41	5,557,894.77	6,469,324.12
	Khu Khat	225005	1708358	Ban Ngiow	6.65	8.34	5,210	5,654	2,605	2,827	1.96	3.12	1,975,015.00	3,159,387.40
	Khu Khat	219948	1706120	Ban Pho Bit	6.43	9.346	7,760	16,754	3,880	8,377	4.89	16.9	7,760,796.12	3,930,955.54
	Mueang Khong	212267	1703423	Ban Don Yai	6.31	9.142	556	14,418	278	7,209	0.27	10.8	1,286,224.68	2,164,920.29
	Mueang Khong	211910	1708271	Ban Nong Khaem	6.3	9.105	10,128	-	5,064	-	4.49	48.4	4,747,632.21	10,584,054.74
	Mueang Khong	211224	1708348	Ban Non Wat	6.37	8.709	14,304	18,512	7,152	9,256	4.4	15.8	4,646,349.39	5,038,820.32
	Ban Prang	187597	1715276	Wat Pa Prang Thong	6.05	9.12	8,541	10,898	4,271	5,449	4.42	16.12	4,488,094.98	5,732,188.04
	Nong Bua	192530	1717177	Ban Ta Kim	6	9.152	1,638	4,542	819	2,271	0.85	3	985,962.12	3,824,059.49
Kham Sakae Saeng	Mueang Kaset	196954	1703106	Ban Rim Bung	6.667	6.79	226	2,104	113	1,052	0.1	0.51	1,050,809.26	1,386,308.61
	Nong Hua Fan	202892	1705899	Ban Nong Hua Fan 1	6.347	6.67	7,434	10,712	3,717	5,356	2.82	14.46	2,911,881.09	9,216,736.66
	Nong Hua Fan	202822	1706078	Ban Nong Hua Fan 2	6.263	6.55	6,380	9,436	3,190	4,718	4.15	5.74	4,177,916.35	5,532,574.07
	Nong Hua Fan	200940	1709601	Ban Non Ban Na	6.627	6.84	256	2,580	128	1,290	0.13	1.01	1,114,111.03	1,709,147.41
	Chiwuek	191176	1698356	Chiwuek temple	6.639	6.72	1,658	10,306	829	5,153	0.86	1.23	215,225.99	745,061.48
	Kham Sakaesaeng	197182	1703411	Ban Nong Jan school	6.46	6.14	5,836	6,040	2,918	3,020	2.43	4.03	2,373,816.11	4,025,992.11
	Kham Sakaesaeng	195905	1700730	Ban Non Jang	6.283	6.91	3,374	5,894	1,687	2,947	1.65	3.94	2,253,542.76	3,962,690.35
	Mueang Nat	206618	1702113	Ban Sema	6.347	6.76	964	3,068	482	1,534	0.5	0.87	1,310,346.49	1,892,722.71
	Mueang Nat	203192	1704728	Mueang Nat temple	6.315	6.53	2,480	5,626	1,240	2,813	1.39	2.56	1,493,921.60	2,677,920.74
	Mueang Nat	206028	1702416	Ban Mueang Nat	6.389	6.48	186	1,004	93	502	0.08	0.72	1,057,139.44	1,569,883.72

Table A2 Chemical properties of groundwater samples according to different seasons.

District	Sub district	UTM E	UTM N	Well no.	Location	pH		EC		TDS		Salinity content		Chloride content	
						Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Non Daeng	Non Daeng	238141	1706668	5705D031	Non Daeng Municipal school	7.58	7.89	3,794	15,288	1,934	7,614	2.02	22.70	3,499.57	51,046.54
	Non Daeng	238343	1705364	5405B007	Phu Wittaya school	7.05	7.97	758	2,458	383	958	0.38	1.00	571.84	1,648.38
	Samphaniang	238705	1711383	NR270	Ban Nong Ya Khao	7.61	7.80	1,830	2,020	917	1,010	0.90	1.07	1,587.46	2,202.90
Non Thai	Banlang	170377	1689973	MG799	Ban Muang Kao school	7.89	7.48	912	2,138	456	1,074	0.44	1.08	276.50	1002
	Banlang	170363	1690249	-	Ban Muang Kao 1	7.60	7.92	1,064	1,804	532	902	0.56	0.87	312.96	872
	Banlang	170357	1688964	-	Ban Muang Kao 2	7.29	7.94	940	970	468	487	0.48	0.89	176.23	894
	Banlang	170013	1689327	-	Ban Muang Kao 3	7.61	7.63	1,180	1,632	590	812	0.58	0.84	518.06	972.32
	Banlang	170683	1689675	SC409	Ban Muang Kao temple	7.97	7.50	798	960	395	483	0.40	0.48	258.27	885.43
	Sai O	181412	1691223	-	Ban Sawai	7.32	7.33	1,774	1,928	887	952	0.27	0.97	161.04	1161.039685
	Thanon Pho	192879	1693814	PW13862	Ban Nong Ta Maen	7.47	7.41	1,022	1,214	511	607	0.59	0.71	543.89	899.21
	Makha	187792	1689952	MG1571	Nong Doom health promoting hospital	8.05	7.86	1,320	1,410	651	705	0.51	0.58	265.11	556.04
Non Sung	Lum Khao	215050	1687249	-	Ban Dong Plong	7.71	7.42	3,960	28,800	1,980	14,400	2.09	7.54	3,760.00	7,540.00
	Lum Khao	209452	1684940	-	Ban Krok Kham	7.32	7.21	1,608	6,148	784	3,074	0.85	3.76	2,303.17	3,548.00
	Than Prasat	222250	1687690	-	Ban Talad Kae	7.26	7.67	1,926	2,128	963	1,064	0.59	1.03	312.57	964.00
	Dan Khla	203592	1674430	-	Ban Bu	7.51	7.56	1,884	2,090	912	1,045	0.48	0.51	102.00	138.00
	Tanot	206821	1671468	D0516	Ban Non Makok	7.78	7.24	6,088	13,440	3,044	6,720	1.50	2.70	1,701.32	3,912.00
	Phon Sungkhram	212794	1698603	-	Ban Salao	7.32	7.12	810	1,970	405	995	0.49	0.96	157.00	203.00
Khong	Non Teng	206847	1708043	MY610	Ban Non Thong	7.43	7.48	896	936	456	467	0.43	0.45	17.85	103.31
	Non Teng	206466	1707680	MY853	Ban Non Thong temple	7.58	7.68	910	1,758	471	879	0.48	0.57	115.46	358.19
	Non Teng	207618	1709139	PW16	Ban Nong Bua Gra Jai school	7.77	7.87	1,584	1,716	792	838	0.79	0.83	43.03	941.93
	Nong Manao	207201	1716400	5805D004	Ban Don Klang school	7.36	7.83	318	494	159	247	0.16	0.25	21.79	358.54
	Nong Manao	206169	1716165	5805A004	Ban Taluk Nam Khwang	7.50	7.50	2,060	3,492	1,030	1,746	1.09	1.98	1,060.43	2,958.42
	Nong Bua	195999	1717793	MG679	Ban Nong Sakae school	7.61	7.74	804	1,732	402	867	0.09	0.86	42.86	948.01
	Nong Bua	197134	1717526	AFD815	Ban Tha Yai 1	7.44	7.54	348	1,008	172	504	0.18	0.55	109.39	293.12
	Nong Bua	197358	1717630	MY619	Ban Tha Yai 2	7.20	7.29	996	1,598	511	799	0.51	0.77	264.35	442.81
	Nong Bua	192508	1717165	5505G052	Ban Ta Kim	7.19	7.44	2,890	4,012	1,487	2,006	1.46	3.3	2,260.63	3,942.48
	Nong Bua	197316	1714455	25111	Ban Ba Dao Rueang	7.52	7.75	2,918	4,344	1,481	2,172	1.55	3.62	2,648.04	4,091.32
	Mueang Khong	214581	1714842	5405B019	Ban Don Du	7.44	7.88	1,498	2,062	777	1,031	0.77	1.01	437.54	1,002.41
	Mueang Khong	214630	1710905	MG1014	Ban Kok Pet 1	7.54	7.70	3,246	4,546	1,699	2,273	1.84	3.01	2,420.15	4,101.25
	Mueang Khong	214775	1711005	MG832	Ban Kok Pet 2	7.63	7.98	1,260	1,842	632	921	0.65	0.91	464.89	1,049.26
	Mueang Khong	215532	1711669	MY327	Ban Kok Pet temple	7.52	7.76	1,208	1,994	602	997	0.63	0.98	288.66	1,101.94
	Ban Prang	184962	1715211	PW20092	Ban Mai Don Tua Pap	7.80	7.99	1,880	3,568	920	1,784	0.91	2.05	805.20	2168.53
	Ban Prang	185261	1715430	MG1017	Ban Don Tua	7.65	7.82	1,690	1,744	849	869	0.08	0.85	41.08	741.39
	Ban Prang	184921	1712189	AFD806	Ban Huay Luek	7.41	7.87	2,052	3,102	1,021	1,551	0.42	0.58	498.31	673.84
	Ban Prang	184934	1710462	5905H052	Ban Thap Ma Kham school	7.73	7.97	4,918	6,808	2,459	3,404	1.80	3.12	3,542.68	6,117.99

Table A2 Chemical properties of groundwater samples according to different seasons (continued).

District	Sub district	UTM E	UTM N	Well no.	Location	pH		EC		TDS		Salinity content		Chloride content	
						Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Kham Sakae Saeng	Non Mueang	191889	1706585	5805B035	Ban Non Mueang school	6.94	7.51	1,046	1,670	515	835	0.51	0.53	215.73	1,095.37
	Non Mueang	188468	1705543	SC1145	Ban Taluk Hin	6.64	7.43	1,020	1,034	490	517	0.24	0.55	227.89	414
	Non Mueang	191207	1708251	MY331	Ban Ngio school	6.57	7.14	2,092	2,114	1,069	1,074	1.06	1.6	1,124.24	1,968.94
	Non Mueang	189356	1706970	MY337	Ban Khum Muang	6.38	7	1,826	1,856	823	988	0.89	0.9	1,051.32	1,076.16
	Non Mueang	191778	1706565	MG320	Ban Sa Kruat	6.55	7.44	1,080	1,576	568	716	0.53	0.56	258.27	683.66
	Mueang Kaset	195665	1706447	5605B031	Ban Khu Mueang school	6.88	7.53	604	1,086	302	537	0.36	0.59	133.69	437.54
	Nong Hua Fan	201683	1706461	5905D059	Chomcho Nong Hua Fan school	6.15	7.47	8,156	8,594	3,940	4,297	4.32	4.38	6,168.12	7,305.28
	Nong Hua Fan	198289	1710131	MY228	Ban Non Makluea temple	6.58	7.21	2,870	3,438	1,435	1,719	1.35	1.43	1,815.49	2,175.90
	Nong Hua Fan	198165	1710145	5505C054	Ban Non Makluea school	6.85	7.34	2,248	2,890	1,247	1,487	1.36	1.48	1,952.23	2,311.79
	Nong Hua Fan	207082	1705864	MG1637	Ban Jod school	6.43	7.66	2,286	3,996	1,166	1,998	1.28	1.45	1,739.53	2,310.77
	Chiwuek	188847	1695635	5905H029	Chiwuek 1	6.68	7.08	738	960	368	480	0.36	0.49	240.04	358.54
	Chiwuek	187952	1700628	5805H044	Chiwuek 2	6.13	6.85	1,989	2,248	995	1,247	0.93	1.39	832.54	2,060.40
	Chiwuek	188906	1696058	PW73	Ban Hua Bung	6.48	6.64	284	1,020	137	490	0.07	0.24	45.58	227.9
	Chiwuek	187583	1697185	MY458	Ban Nong Pho	6.5	6.57	1,278	2,092	637	1,069	0.64	0.81	525.66	948.01
	Chiwuek	186671	1698911	5805H049	Ban Non Phak Chi school	6.18	6.19	2,228	2,890	1,150	1,487	1.19	1.43	1,450.88	2,217.99
	Kham Sakaesaeng	201285	1698994	MG1441	Ban Nook 1	6.78	6.92	960	1,178	498	587	0.51	0.99	595.54	1,266.29
	Kham Sakaesaeng	201393	1698950	MG1442	Ban Nook 2	6.08	6.13	960	4,002	480	2,050	0.49	0.88	376.77	805.2
	Kham Sakaesaeng	200904	1699036	MG1443	Ban Nook school	6.78	7.19	2,160	3,204	1,082	1,602	1.15	1.31	1,190.33	1,777.51
	Kham Sakaesaeng	203193	1699010	MG318	Ban Namab	6.52	7	1,086	1,200	537	600	0.29	0.59	443.62	734.55
	Kham Sakaesaeng	196920	1694693	AFD998	Ban Bu La Kro	6.53	6.7	1,682	2,894	842	1,447	0.88	0.97	786.97	1,253.37
	Mueang Nat	208529	1701210	5705B005	Ban Sema school	6.07	6.98	2,532	2,998	1,266	1,494	1.19	1.42	1,815.49	1,975.01
	Mueang Nat	204767	1699728	AA1655	Ban Nong Pho Namab school	6.36	6.52	366	1,086	184	537	0.25	0.51	237	492.48

Table A3 Chemical properties of surface water samples according different seasons.

District	Sub district	UTM E	UTM N	Location	pH		EC		TDS		Salinity content		Chloride content	
					Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Non Daeng	Non Daeng	231234	1710843	Non Ta Then reservoir	7.18	7.80	2,716	3,182	1,366	1,591	1.42	1.48	2,581.95	2,856.18
	Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	7.63	7.89	9,676	11,912	4,838	5,956	2.41	7.54	4,430.11	20,281.88
	Samphaniang	237465	1711266	Huai Fang	7.28	7.43	1,060	4,358	530	2,164	0.65	0.93	934.33	1,328.16
Non Thai	Dan Chak	188274	1678720	Ban Dan Chak reservoir	7.21	7.35	2,774	2,870	1,392	1,467	1.45	2.32	2,582.71	3,671.25
	Non Thai	183315	1680970	Don Bot temple reservoir	7.47	7.54	4,860	5,066	2,448	2,533	2.71	3.19	5,052.24	6,897.36
Non Sung	Bing	210826	1674312	Bing reservoir	7.44	7.71	2,846	6,088	1,423	3,044	1.34	4.98	2,303.17	9,799.11
	Than Prasat	219142	1688112	Lum Than Prasat river (Ban Mai Kasem Tai)	7.52	7.78	1,970	2,128	995	1,064	0.96	1.03	1,684.99	1,800.30
	Don Chomphu	215493	1682185	Lum Chiang Krai river (Ban Som)	7.39	7.54	1,884	1,608	912	784	0.94	0.95	1,442.52	1,501.01
Khong	Khu Khat	222394	1706686	Kud Vien reservoir	7.13	7.63	352	730	176	365	0.88	0.93	1,161.04	1,452.77
	Mueang Khong	211620	1702627	Bueng Don Yai reservoir	7.83	7.96	984	992	494	496	0.05	0.55	42.49	695.81
	Kham Sombun	221489	1700984	Non Si Fun reservoir	7.55	7.69	284	483	142	242	0.06	0.15	54.69	230.43
Kham Sakae Saeng	Kham Sakaesaeng	196920	1694693	Ban Bu La Kro reservoir	7.31	7.83	1,522	1,704	761	844	0.90	0.99	1,276.16	1,800.30
	Kham Sakaesaeng	195785	1701679	Ban Yakha Non Jang school reservoir	7.01	7.12	4,160	6,066	2,080	2,992	2.75	4.15	5,393.31	8,380.90
	Kham Sakaesaeng	197128	1703284	Non Lan canal	7.16	7.20	1332	2,544	666	1,266	0.68	1.38	917.62	2,546.25

APPENDIX B

X-RAY DIFFRACTOMETER (XRD) DATA

X-ray diffractometer (XRD) data of soil samples

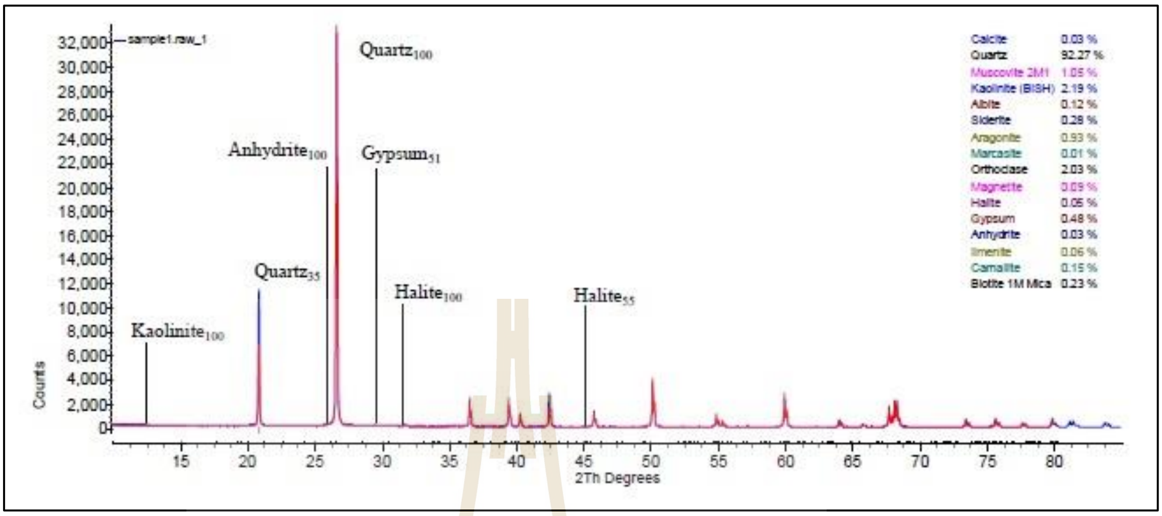

Figure B.1 Interpretation of X-Ray Diffractometer analysis from site number 1.

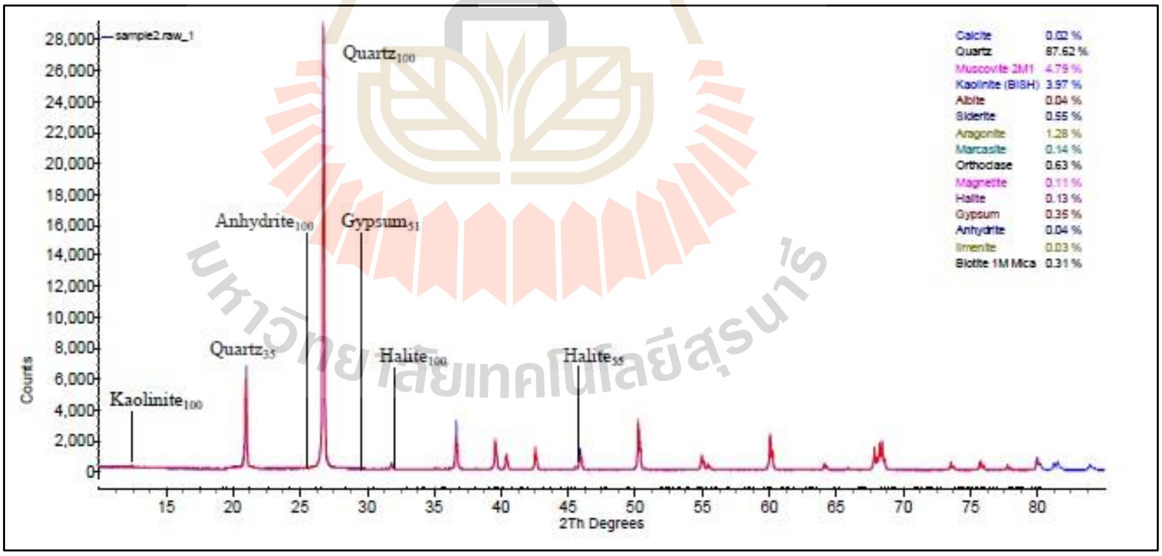

Figure B.2 Interpretation of X-Ray Diffractometer analysis from site number 2.

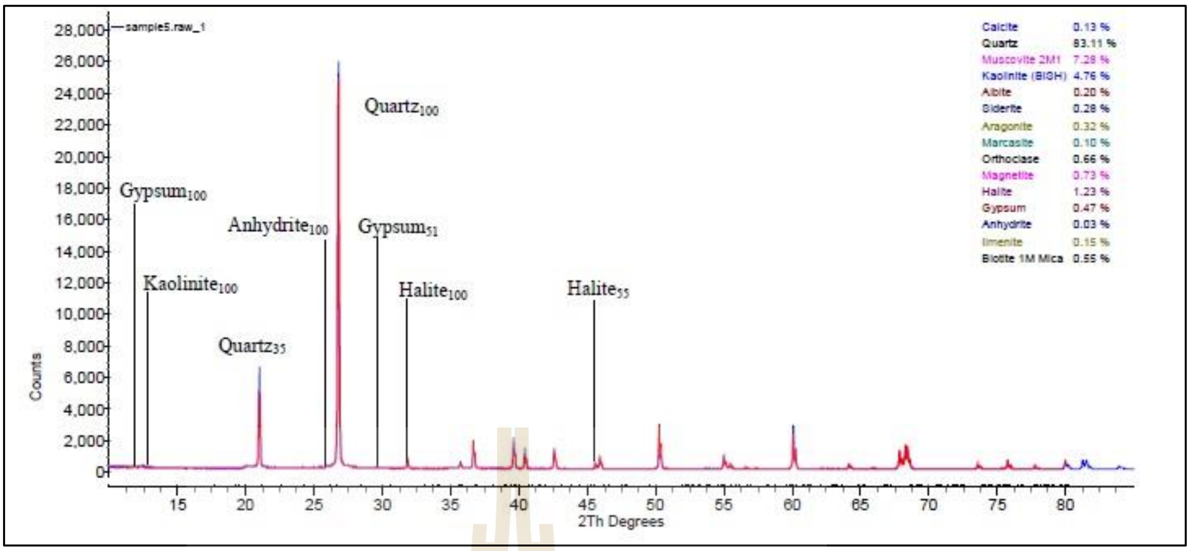

Figure B.3 Interpretation of X-Ray Diffractometer analysis from site number 5.

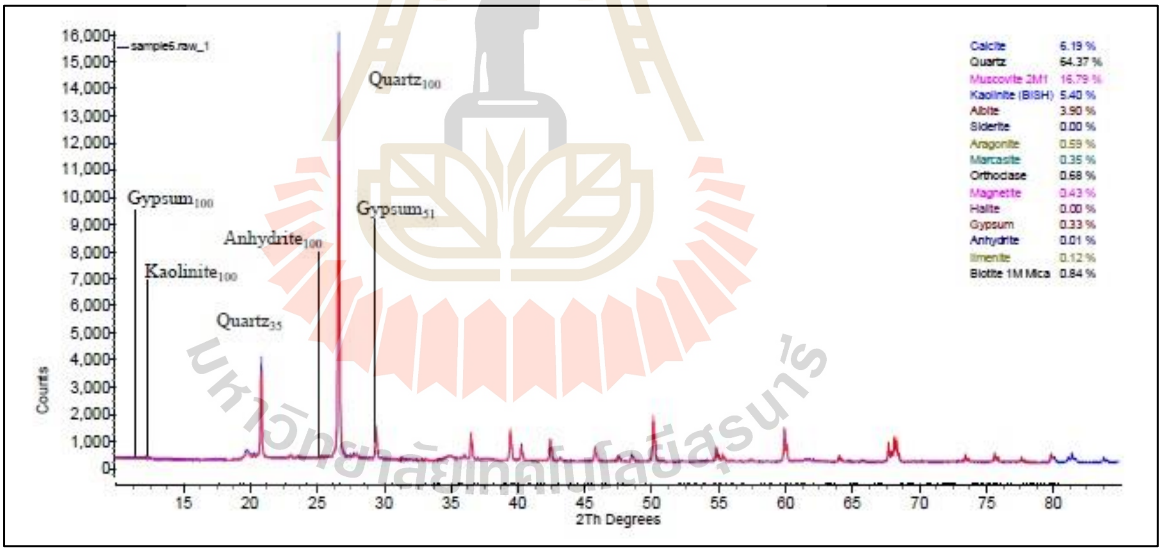

Figure B.4 Interpretation of X-Ray Diffractometer analysis from site number 6.

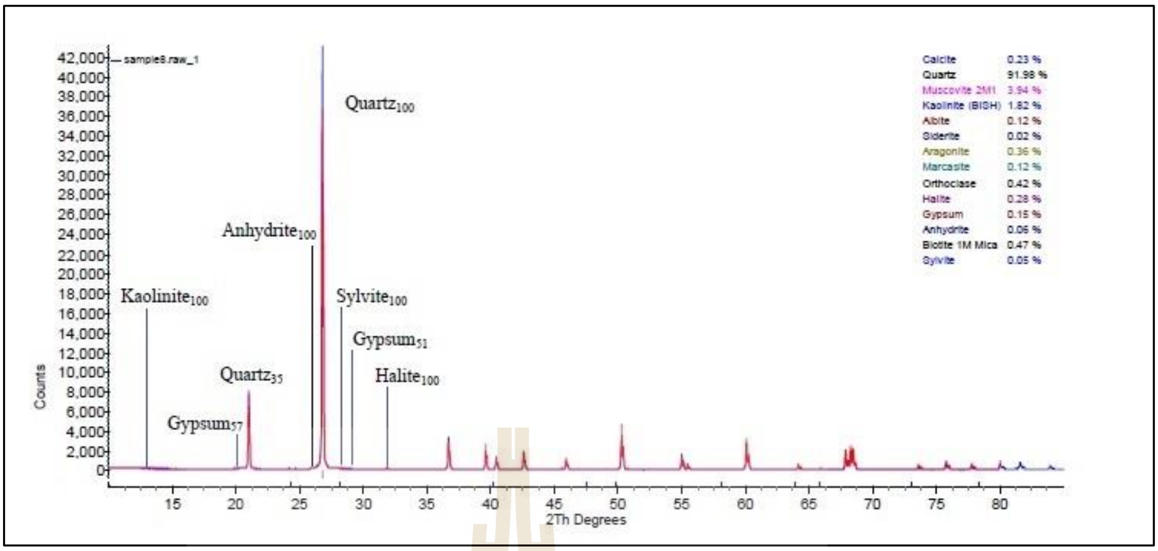

Figure B.5 Interpretation of X-Ray Diffractometer analysis from site number 8.

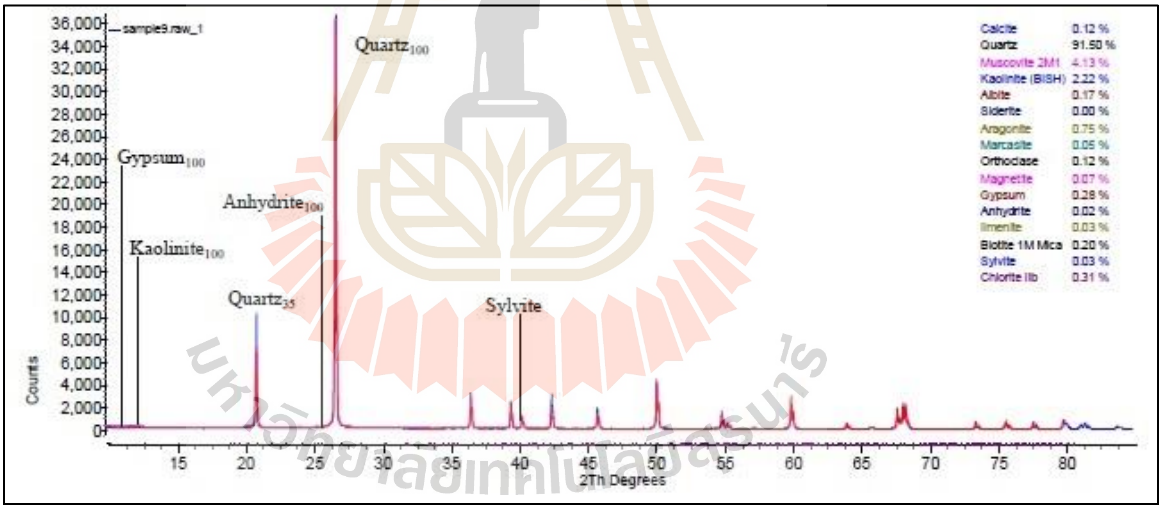

Figure B.6 Interpretation of X-Ray Diffractometer analysis from site number 9.

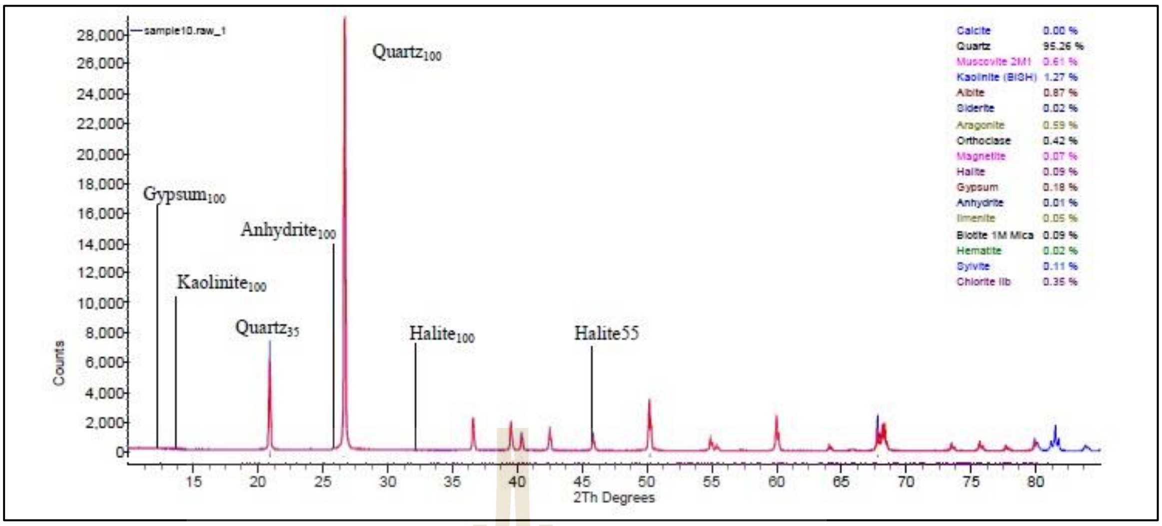

Figure B.7 Interpretation of X-Ray Diffractometer analysis from site number 10.

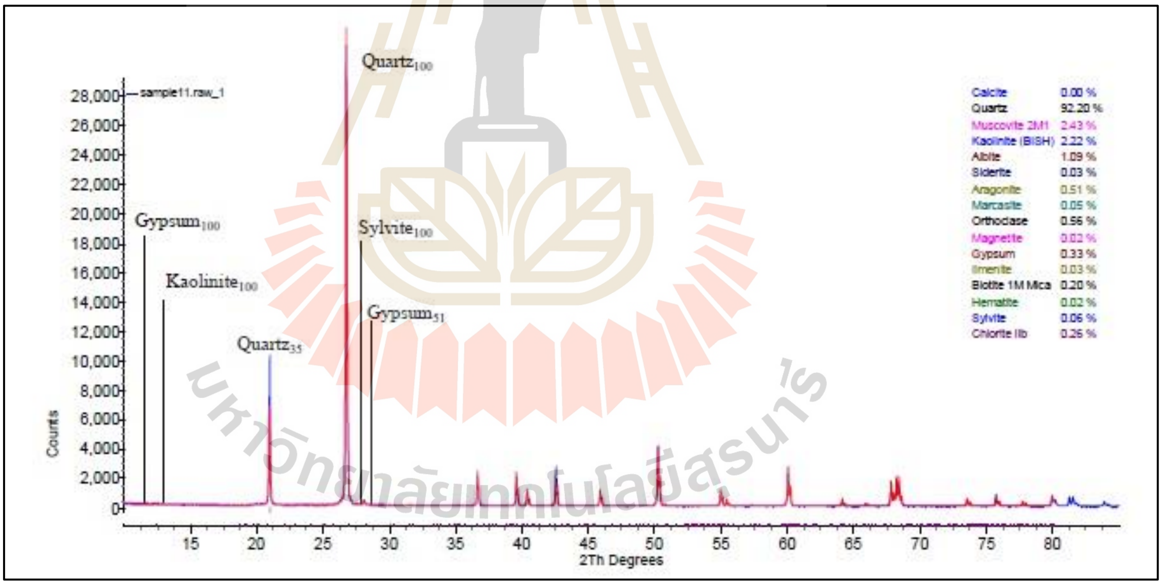

Figure B.8 Interpretation of X-Ray Diffractometer analysis from site number 11.

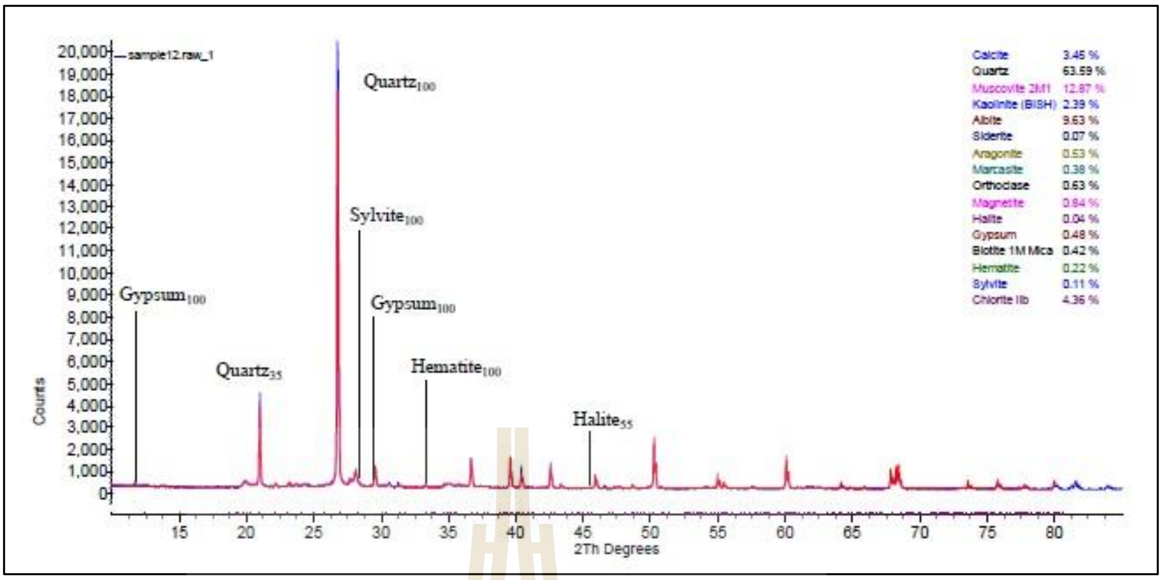

Figure B.9 Interpretation of X-Ray Diffractometer analysis from site number 12.

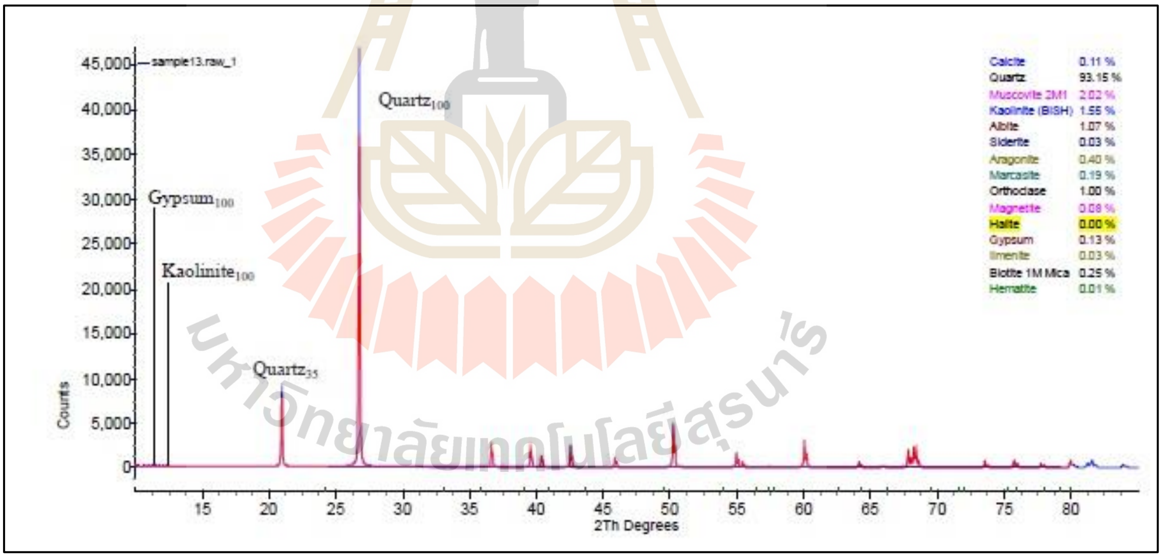

Figure B.10 Interpretation of X-Ray Diffractometer analysis from site number 13.

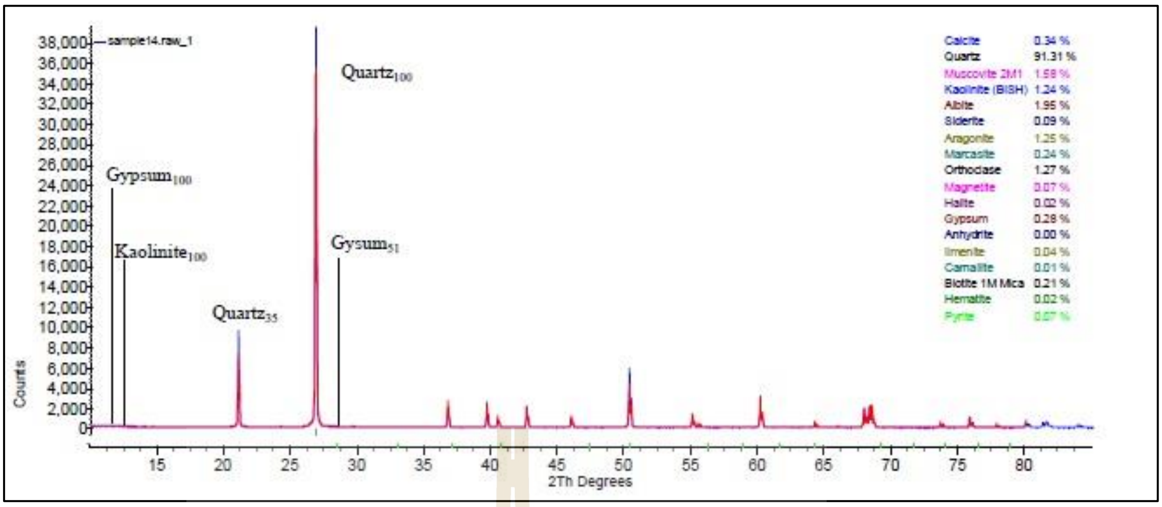

Figure B.11 Interpretation of X-Ray Diffractometer analysis from site number 14.

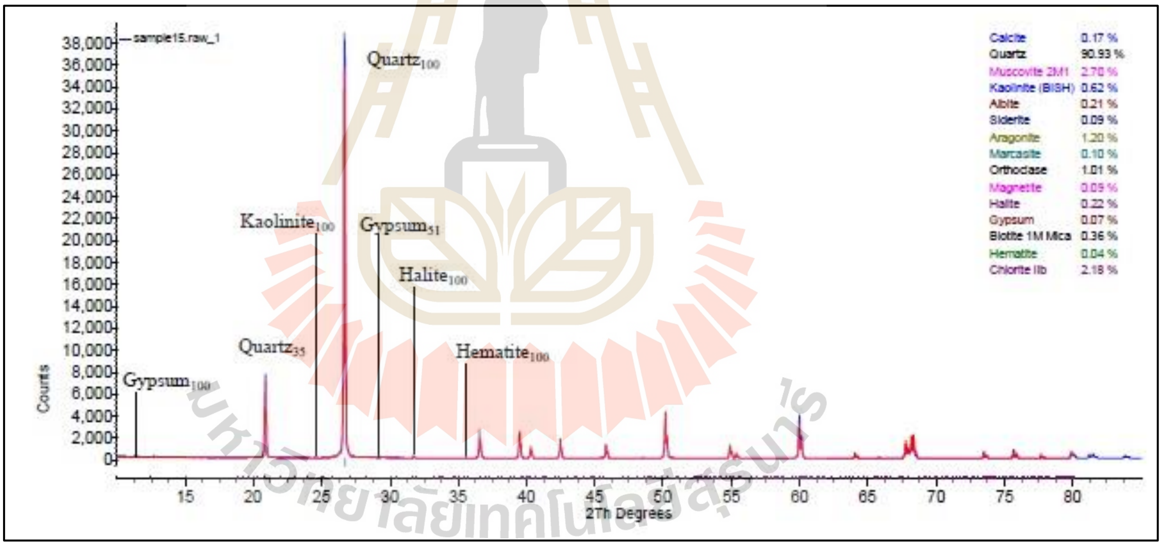

Figure B.12 Interpretation of X-Ray Diffractometer analysis from site number 15.

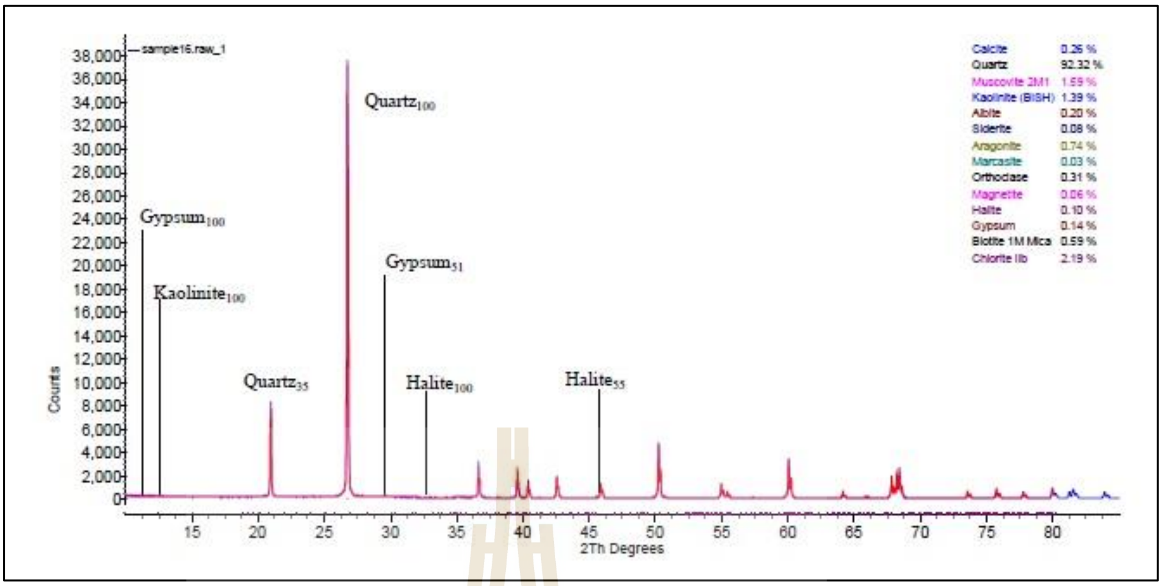

Figure B.13 Interpretation of X-Ray Diffractometer analysis from site number 16.

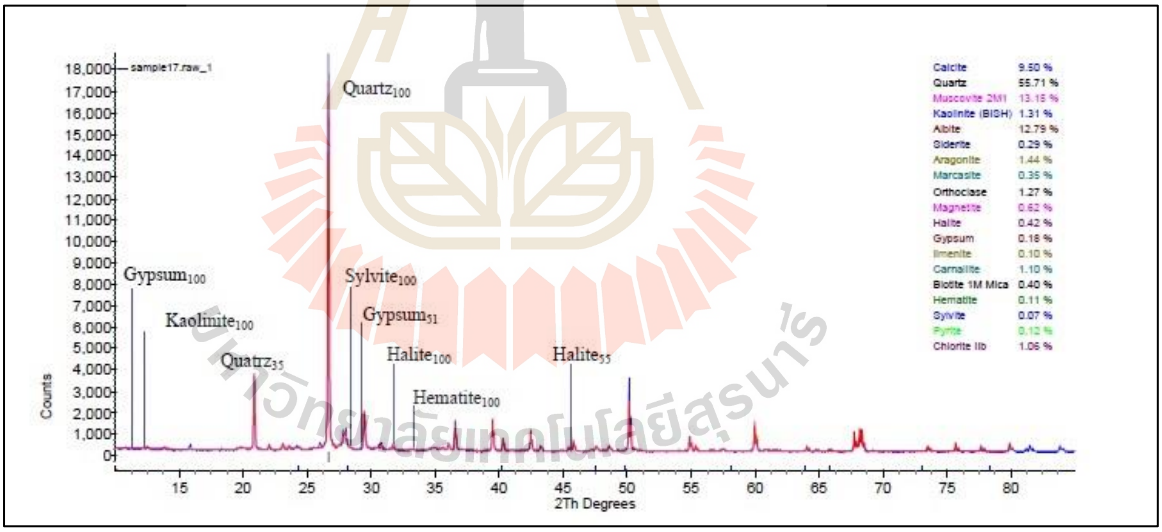

Figure B.14 Interpretation of X-Ray Diffractometer analysis from site number 17.

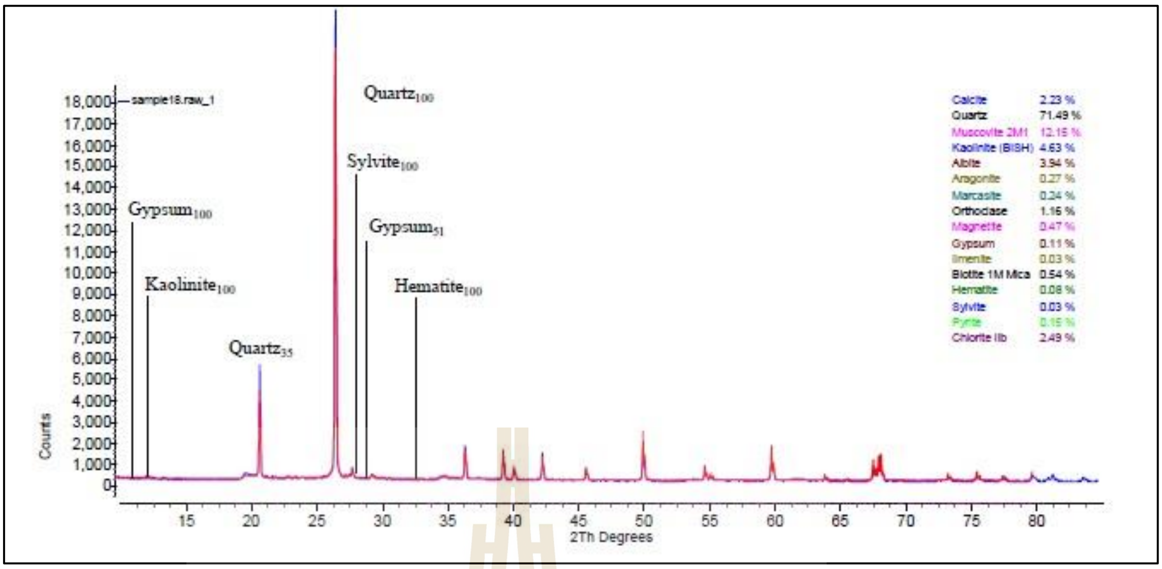

Figure B.15 Interpretation of X-Ray Diffractometer analysis from site number 18.

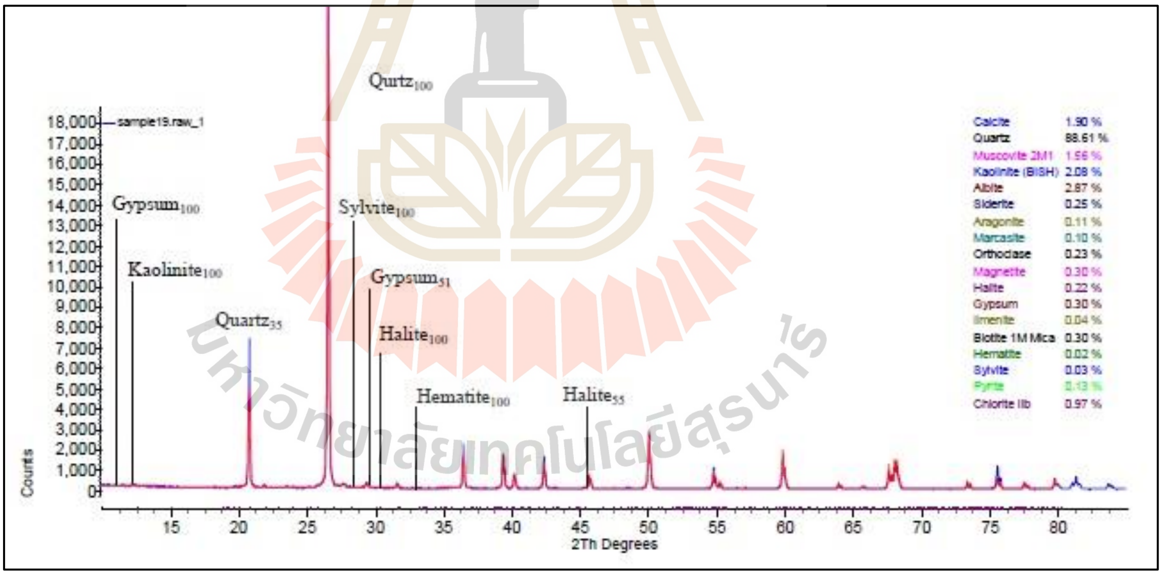

Figure B.16 Interpretation of X-Ray Diffractometer analysis from site number 19.

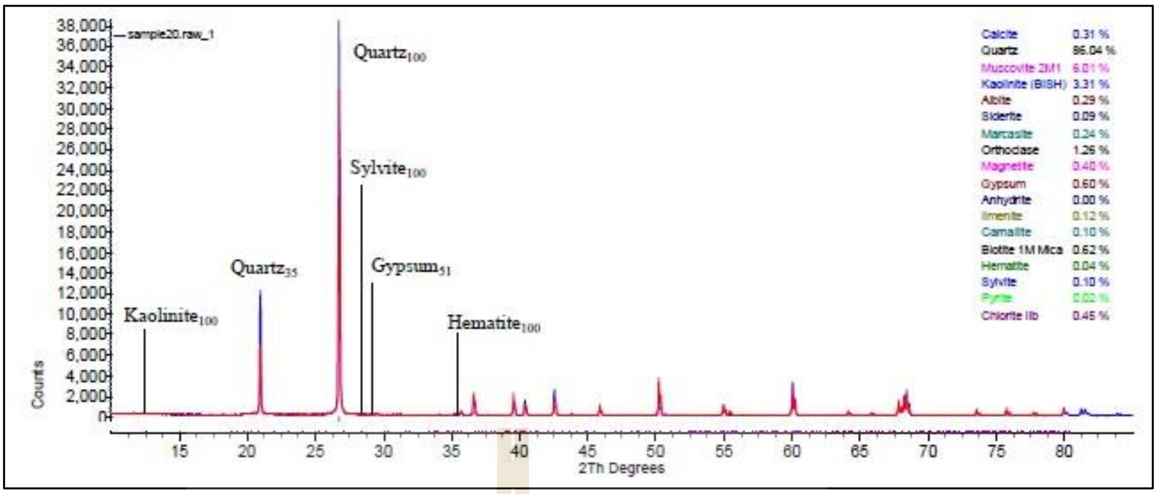

Figure B.17 Interpretation of X-Ray Diffractometer analysis from site number 20.

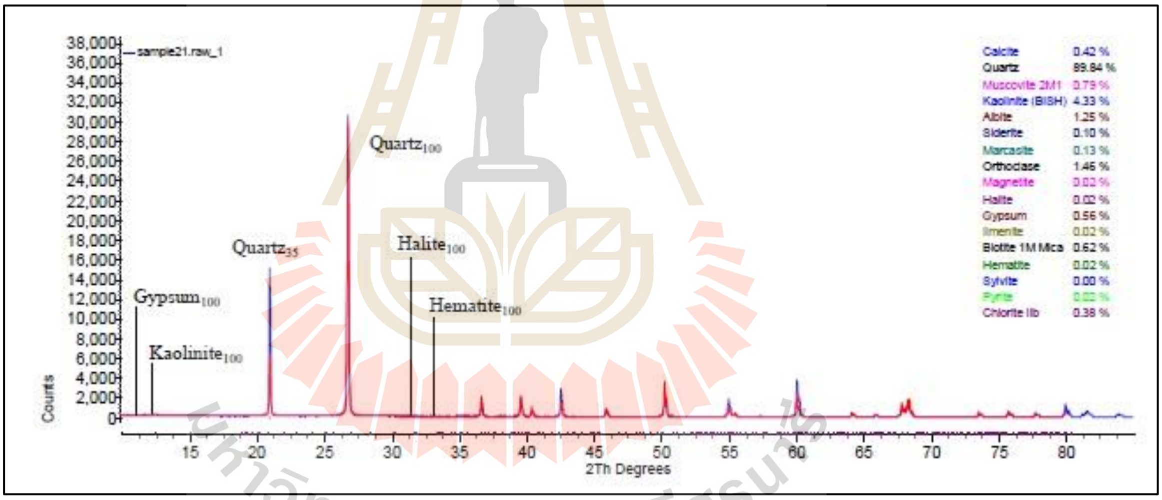

Figure B.18 Interpretation of X-Ray Diffractometer analysis from site number 21.

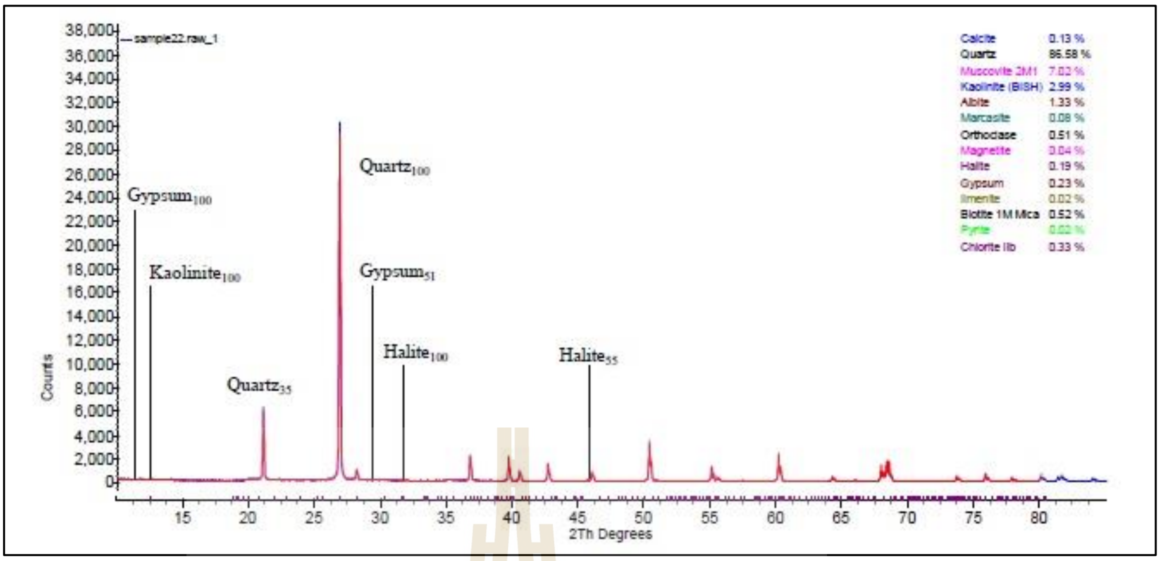

Figure B.19 Interpretation of X-Ray Diffractometer analysis from site number 22.

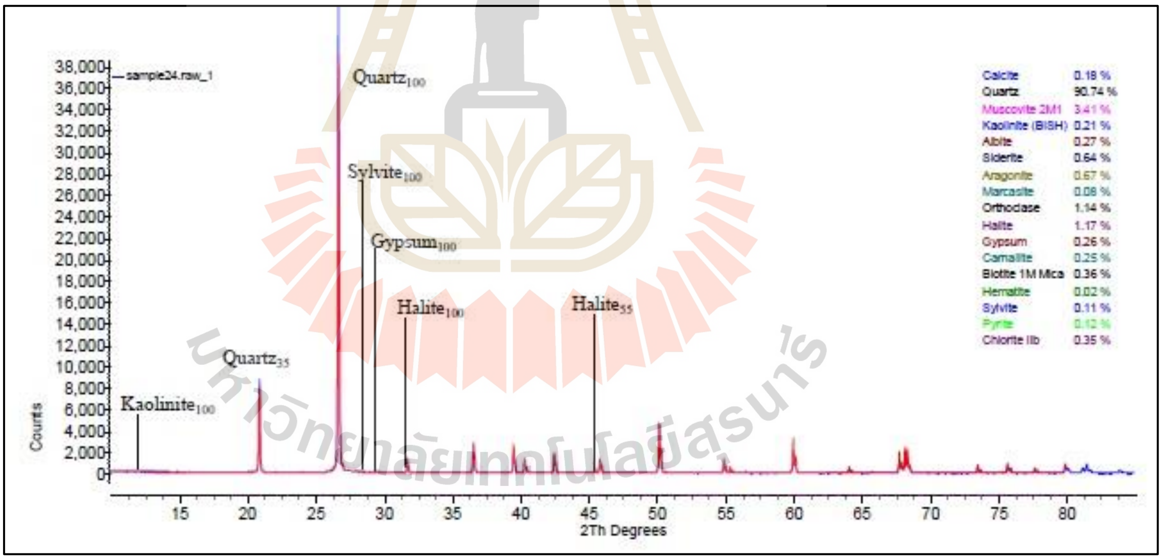

Figure B.20 Interpretation of X-Ray Diffractometer analysis from site number 24.

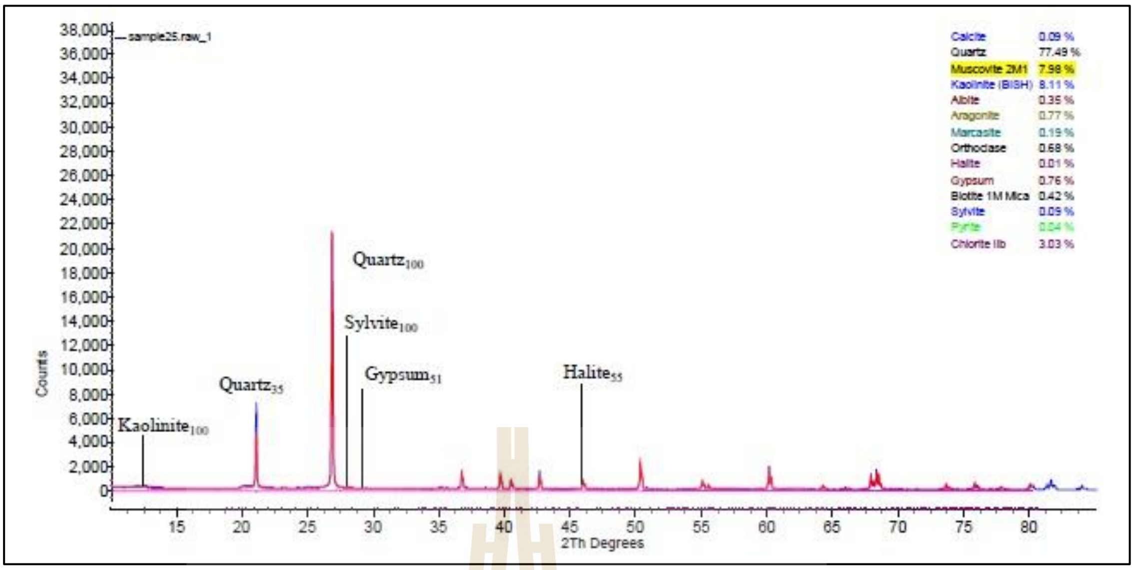

Figure B.21 Interpretation of X-Ray Diffractometer analysis from site number 25.

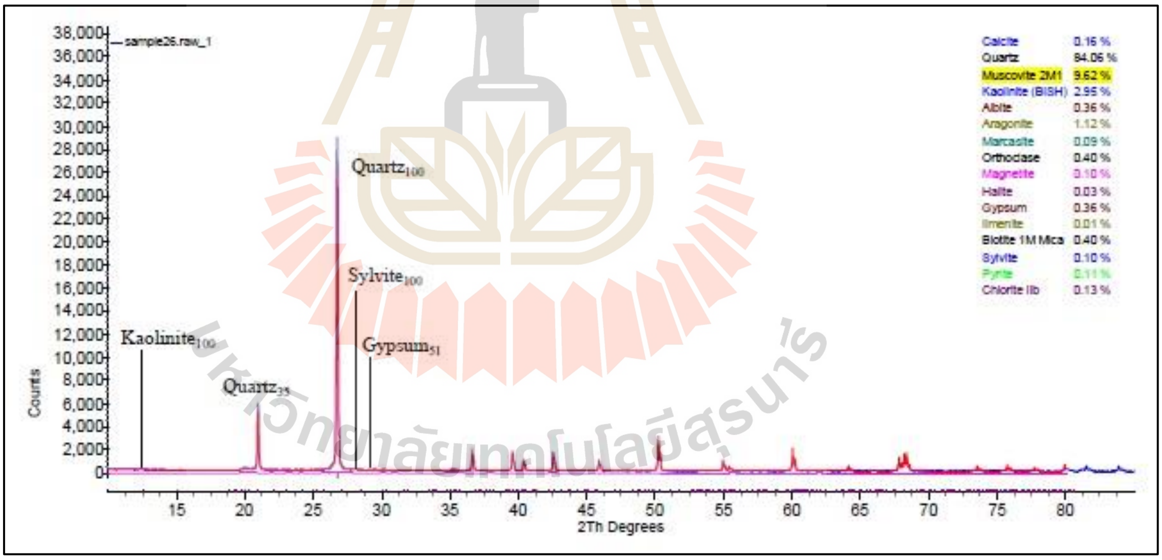

Figure B.22 Interpretation of X-Ray Diffractometer analysis from site number 26.

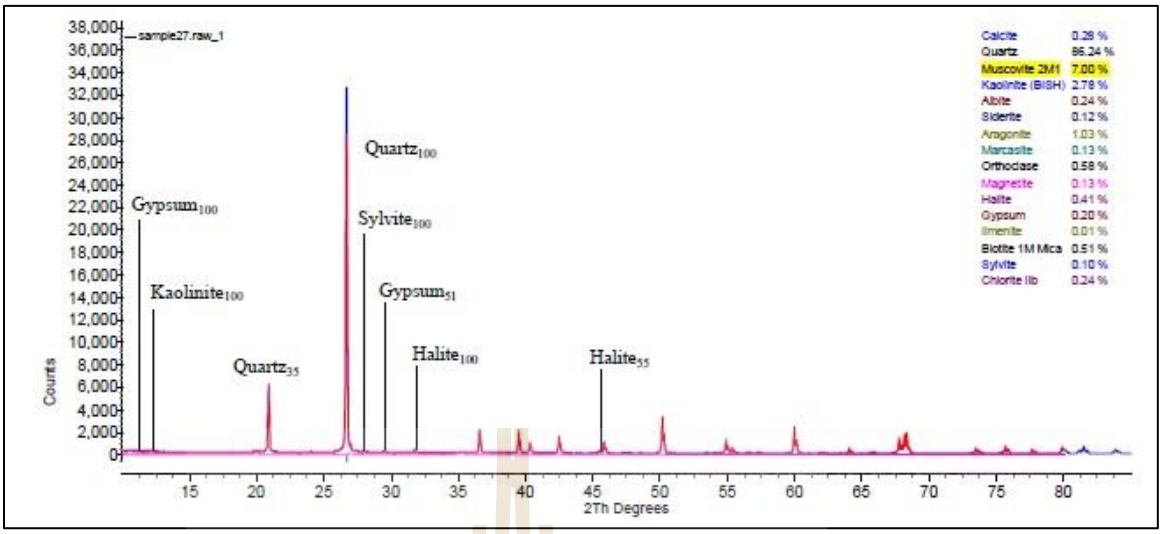

Figure B.23 Interpretation of X-Ray Diffractometer analysis from site number 27.

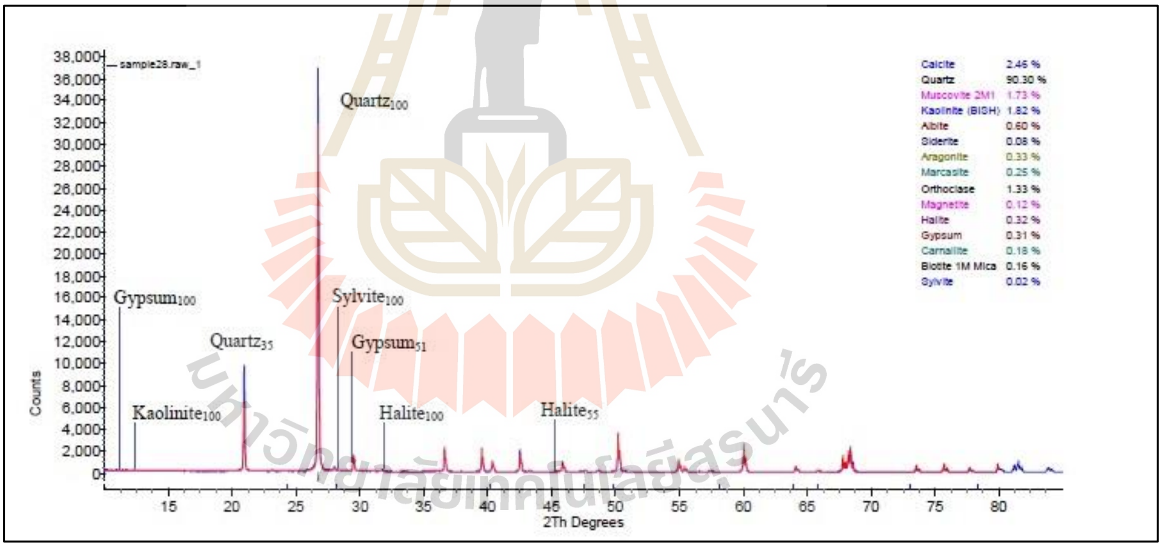

Figure B.24 Interpretation of X-Ray Diffractometer analysis from site number 28.

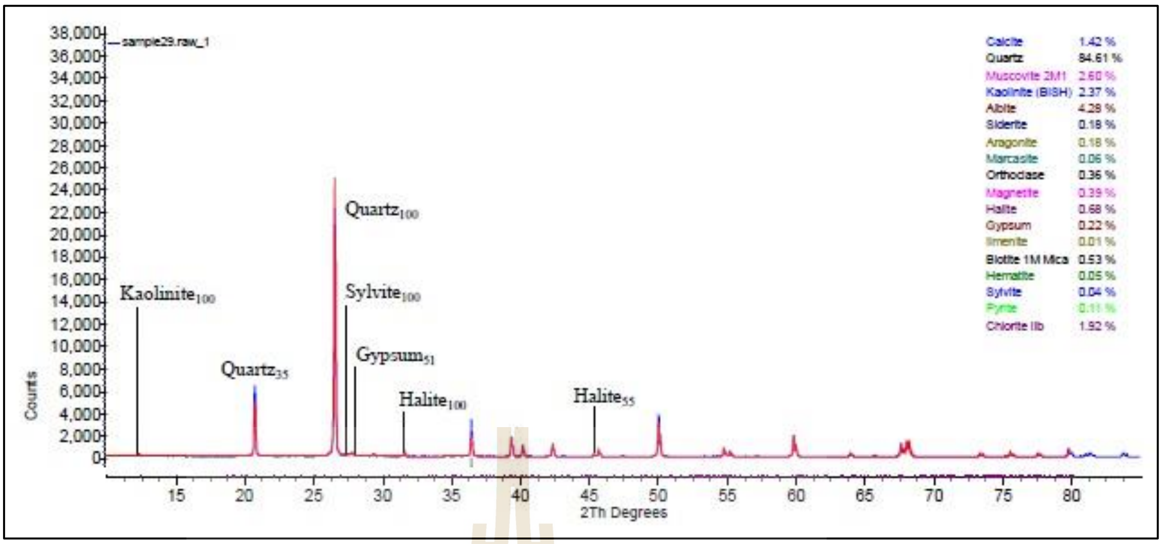

Figure B.25 Interpretation of X-Ray Diffractometer analysis from site number 29.

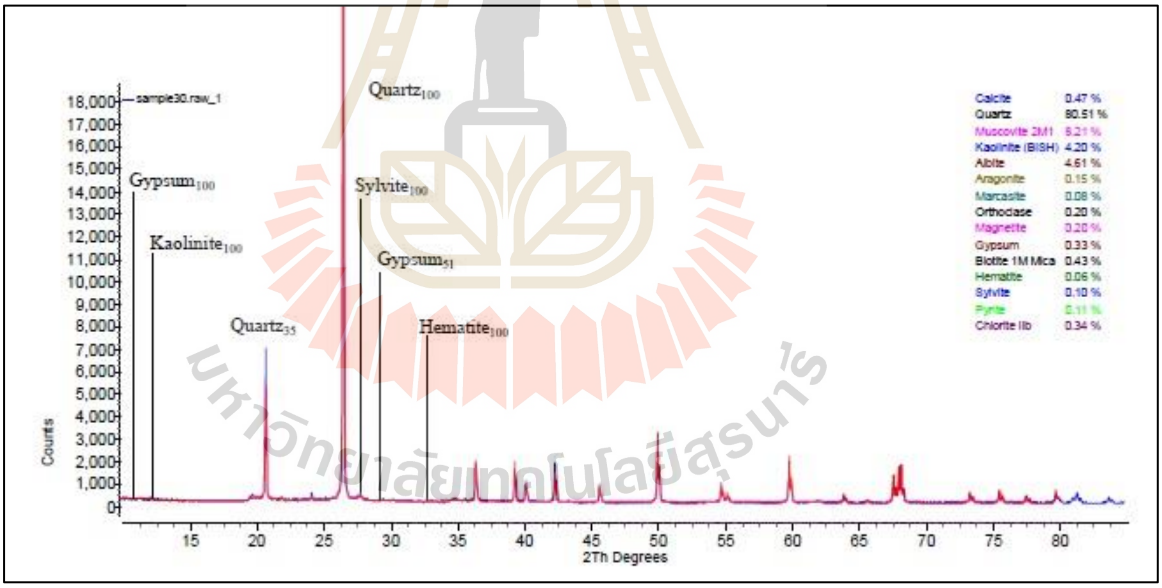

Figure B.26 Interpretation of X-Ray Diffractometer analysis from site number 30.

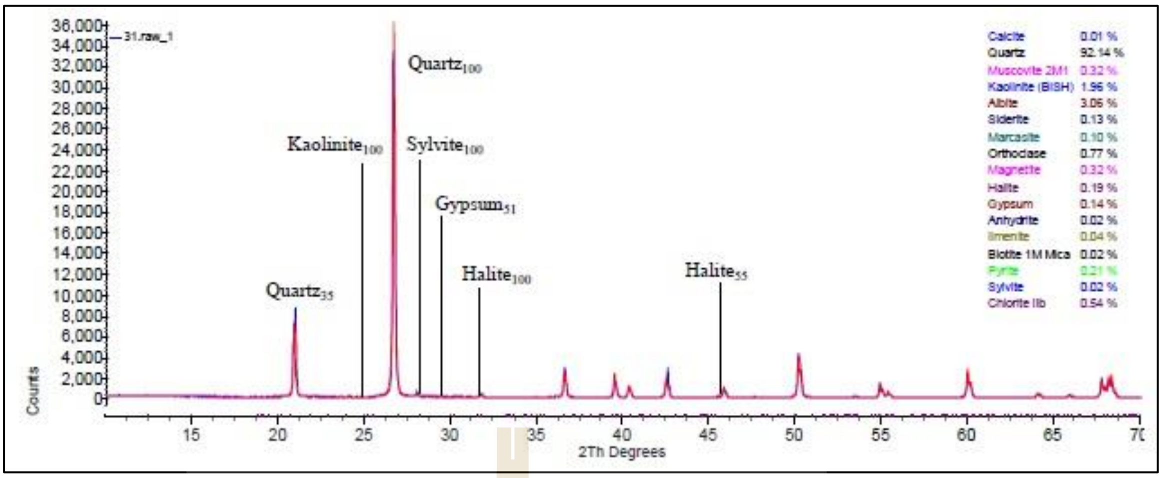

Figure B.27 Interpretation of X-Ray Diffractometer analysis from site number 31.

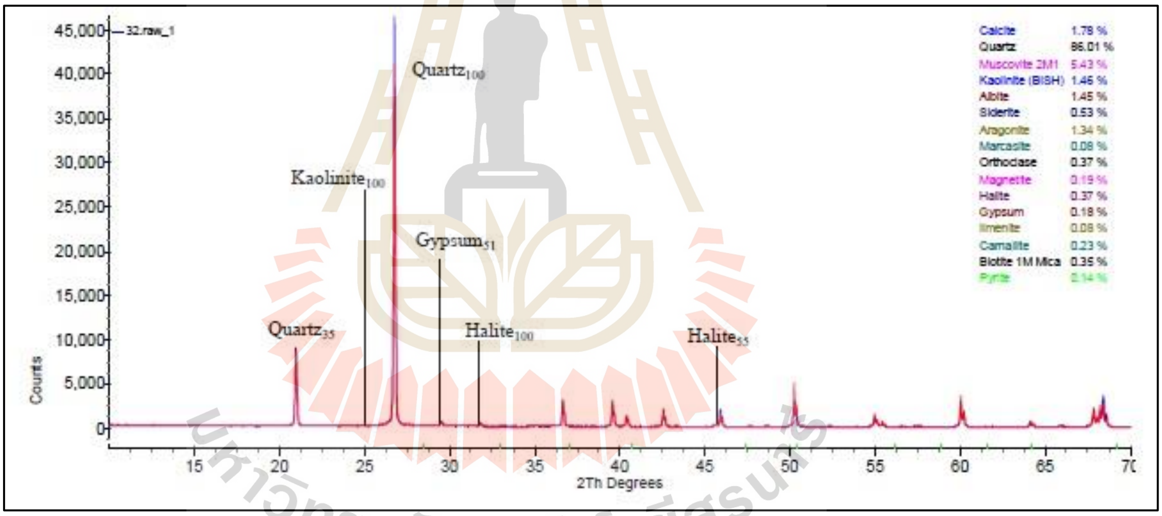

Figure B.28 Interpretation of X-Ray Diffractometer analysis from site number 32.

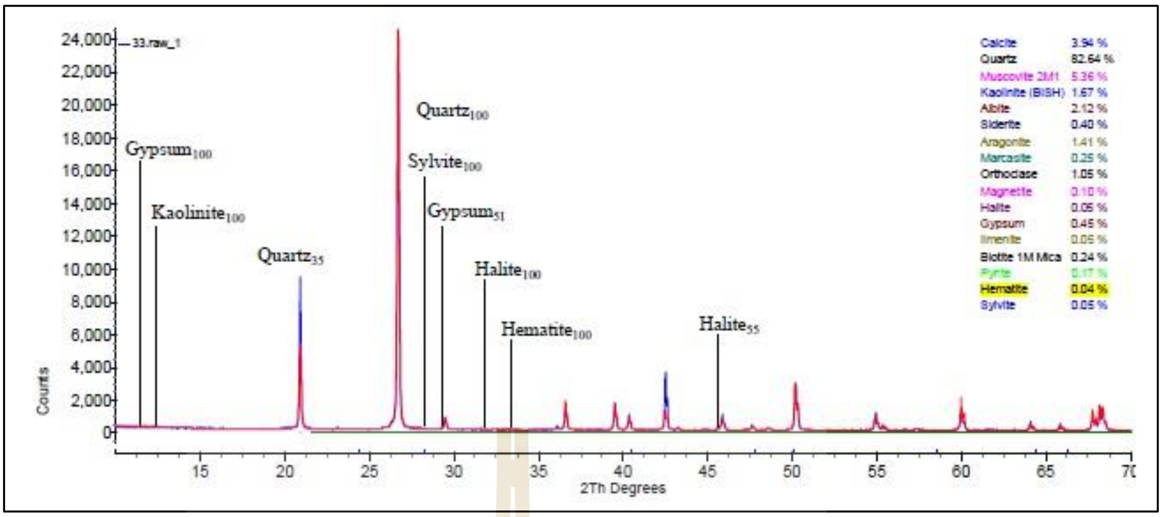

Figure B.29 Interpretation of X-Ray Diffractometer analysis from site number 33.

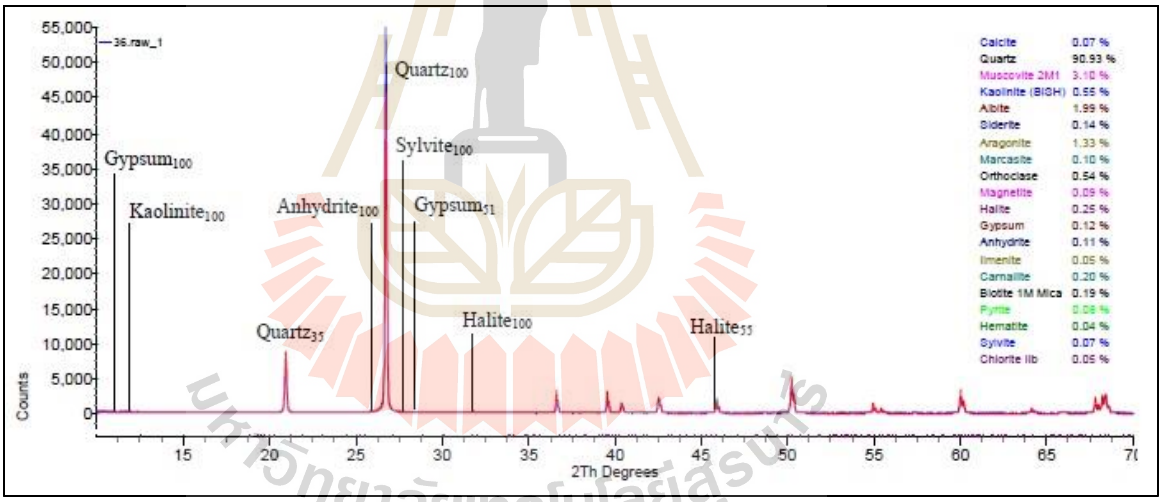

Figure B.30 Interpretation of X-Ray Diffractometer analysis from site number 36.

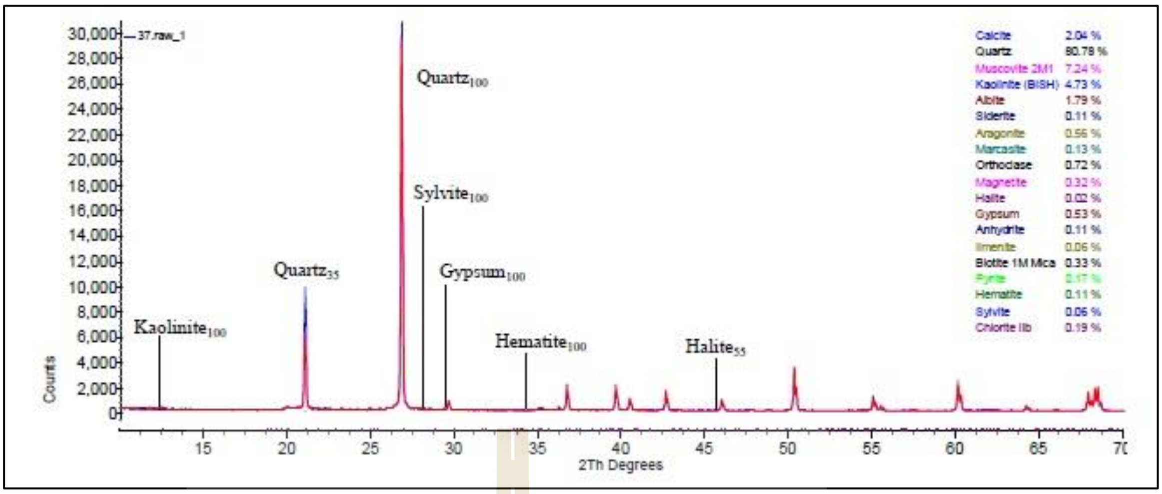

Figure B.31 Interpretation of X-Ray Diffractometer analysis from site number 37.

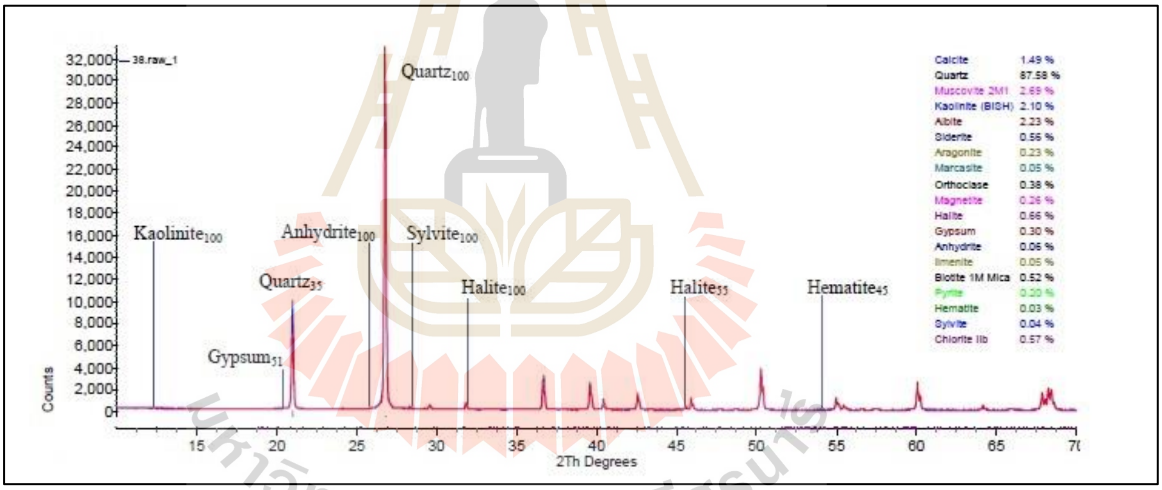

Figure B.32 Interpretation of X-Ray Diffractometer analysis from site number 38.

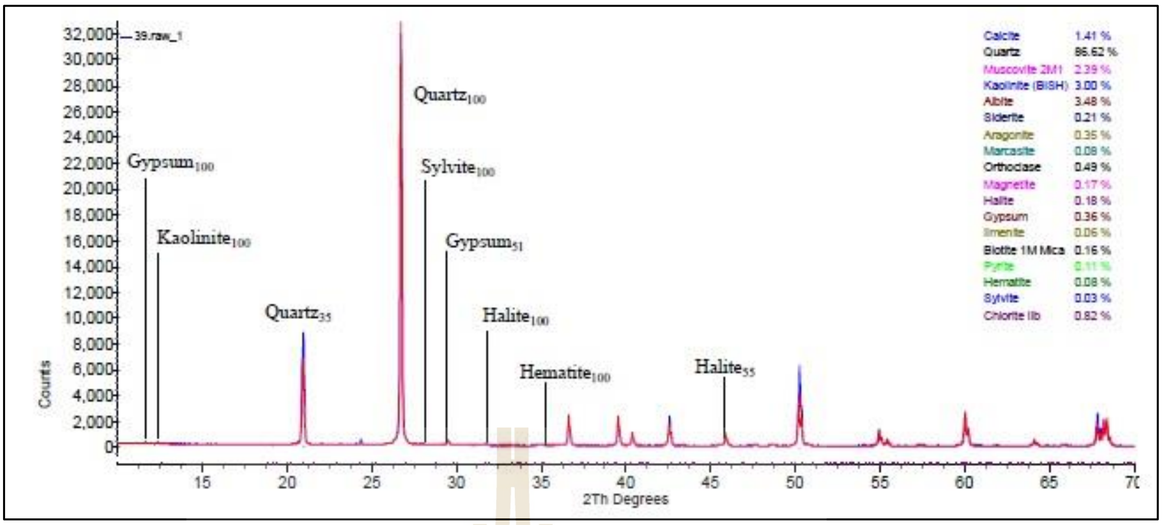

Figure B.33 Interpretation of X-Ray Diffractometer analysis from site number 39.

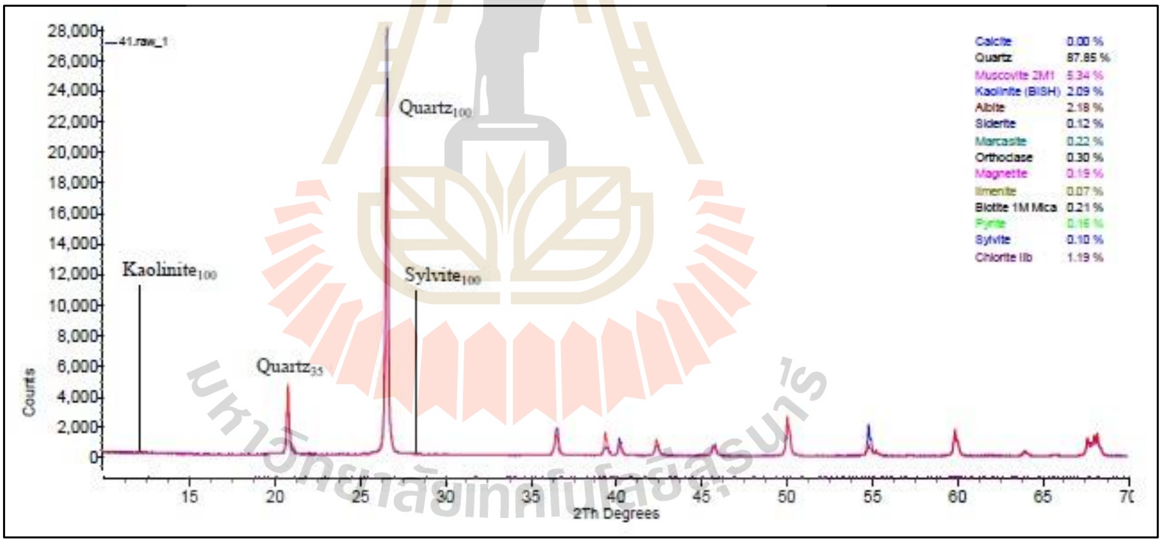

Figure B.34 Interpretation of X-Ray Diffractometer analysis from site number 41.

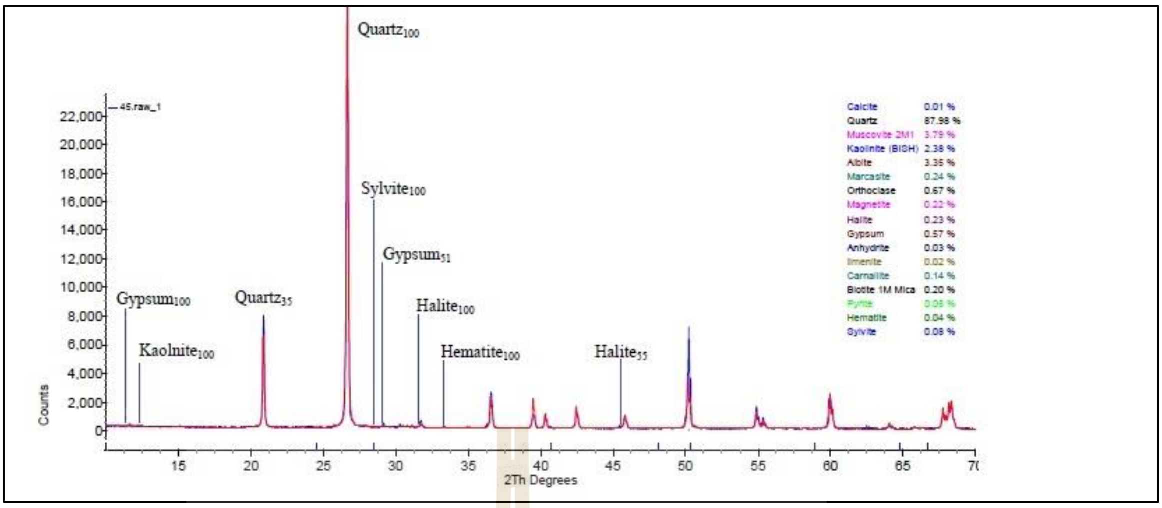

Figure B.35 Interpretation of X-Ray Diffractometer analysis from site number 45.

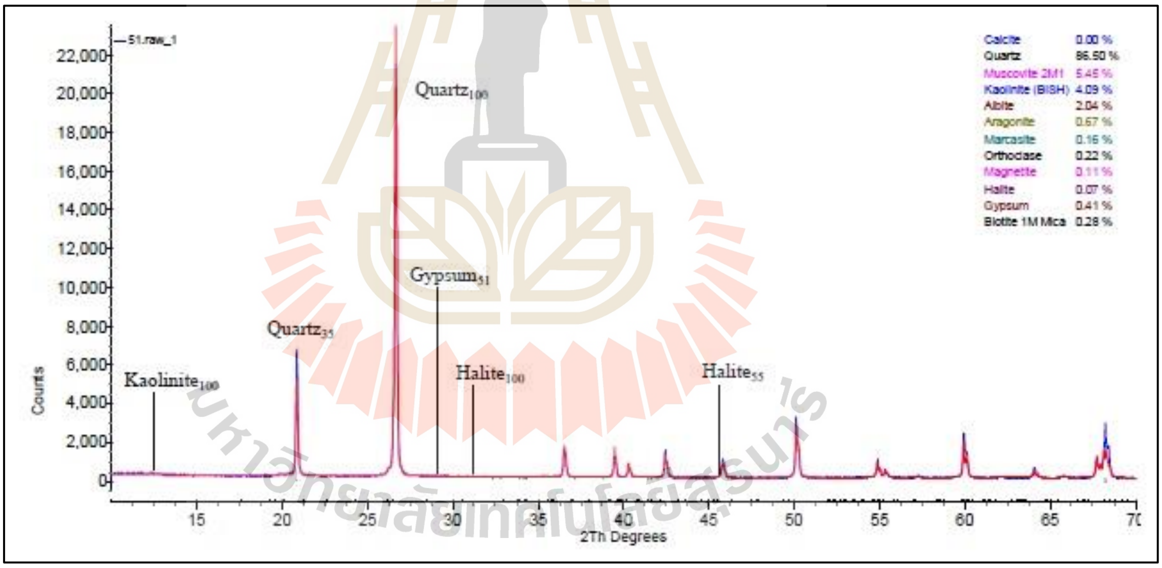

Figure B.36 Interpretation of X-Ray Diffractometer analysis from site number 51.

APPENDIX C

X-RAY FLUORESCENCE (XRF) DATA

X-Ray Fluorescence (XRF) data of soil samples

Table C1 X-Ray Fluorescence (XRF) data of soil samples.

District	Location	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	Co_3O_4	NiO	ZrO_2	PbO	Cs_2O	CuO	BaO	CeO_2	HfO_2	Total
Non Daeng	Ban Don Yao Yai	0.052	0.000	0.000	84.354	0.043	0.132	0.936	1.316	3.678	7.069	0.000	1.901	0.519	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Don Yao Yai health promoting hospital	0.074	0.000	0.000	56.715	0.201	0.400	16.090	0.680	6.483	6.711	0.000	0.750	6.542	0.000	0.000	0.000	0.000	5.354	0.000	0.000	0.000	0.000	100
	Ban Ra Han Kai	0.065	0.000	0.278	39.965	0.939	0.613	4.548	4.397	8.337	7.824	0.000	0.831	31.583	0.000	0.000	0.000	0.000	0.000	0.000	0.620	0.000	0.000	100
	Ban Pa Ta Bang	0.077	0.000	0.032	74.876	0.000	0.000	1.523	0.476	2.159	9.421	0.000	0.906	10.530	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Samphaniang Mai	0.095	0.000	0.000	77.437	0.000	0.000	1.383	0.975	9.880	8.632	0.000	1.153	0.445	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Na Khu temple	0.058	0.000	0.057	64.167	0.345	0.214	0.000	2.879	13.738	8.057	0.319	0.552	9.614	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Hua Talad	0.061	0.000	0.263	68.656	1.161	0.230	1.628	0.661	2.940	9.303	0.000	0.353	12.631	0.000	0.000	0.271	0.000	1.842	0.000	0.000	0.000	0.000	100
	Ban Fang school	0.064	0.000	0.291	71.418	1.213	0.314	2.183	0.894	5.642	8.967	0.000	0.473	8.541	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Toie	0.078	0.000	1.080	59.244	1.114	0.443	2.411	2.140	4.911	6.701	0.000	0.305	18.242	0.000	0.000	0.129	0.000	3.202	0.000	0.000	0.000	0.000	100
	Ban Toie temple	0.087	0.000	0.251	35.091	0.789	0.474	7.771	4.297	6.440	6.115	0.000	0.802	34.764	0.206	0.000	0.000	0.000	2.913	0.000	0.000	0.000	0.000	100
	Ban Hin Tang	0.065	0.000	0.457	69.480	1.240	0.184	5.633	0.705	4.215	4.448	0.000	0.000	12.558	0.000	0.000	0.000	0.000	1.015	0.000	0.000	0.000	0.000	100
	Ban Non Ta Then	0.083	0.000	0.000	76.974	0.099	0.056	0.613	2.871	10.572	5.731	0.000	1.123	1.878	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Non Ta Then temple	0.091	0.000	1.466	58.803	1.215	0.780	4.243	1.887	6.107	3.055	0.000	0.618	21.735	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Non Noi	0.079	0.000	0.059	61.530	0.317	0.303	3.100	1.033	16.819	3.305	0.000	0.408	13.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
Non Thai	Ban Dan Chak	0.000	0.000	0.906	63.449	1.104	0.213	2.853	1.619	15.721	2.557	0.000	0.250	11.199	0.000	0.000	0.129	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Dan Chak temple	0.100	0.000	0.246	71.492	0.532	0.149	1.441	0.562	8.140	3.456	0.000	0.672	13.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Sai Mit Non Thai school	0.000	0.061	1.283	41.751	0.462	0.105	1.312	3.700	23.308	2.877	0.000	0.931	22.883	0.080	0.000	0.044	0.000	0.958	0.000	0.245	0.000	0.000	100
	Ban Song Tham	0.000	0.000	1.190	69.818	1.251	0.401	4.876	0.891	7.689	3.320	0.000	0.410	9.308	0.000	0.000	0.000	0.000	0.846	0.000	0.000	0.000	0.000	100
	Ban Nong Krad	0.000	0.000	0.000	72.179	0.150	0.210	4.552	1.230	9.034	7.621	0.000	2.470	1.056	0.000	0.000	0.000	0.000	1.498	0.000	0.000	0.000	0.000	100
Non Sung	Ban Jan Dum 1	0.000	0.000	0.000	50.911	0.308	0.155	6.725	1.132	21.163	5.767	0.000	2.696	10.235	0.000	0.000	0.000	0.000	0.000	0.000	0.908	0.000	0.000	100
	Ban Jan Dum 2	0.000	0.000	0.531	47.873	0.530	0.282	2.310	2.251	18.146	5.176	0.000	1.828	20.740	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	100
	Ban Chad	0.000	0.000	0.529	35.220	0.637	0.173	3.511	0.594	36.818	2.555	0.000	1.881	17.543	0.000	0.000	0.000	0.000	0.000	0.126	0.227	0.186	0.000	100
	Ban Bing	0.000	0.000	0.737	85.060	1.195	0.393	4.714	0.126	1.944	1.429	0.000	0.000	4.269	0.000	0.000	0.133	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Pet	0.045	0.060	1.491	69.843	1.029	0.216	5.231	0.678	10.073	2.257	0.000	0.203	6.515	0.000	0.000	0.091	1.338	0.930	0.000	0.000	0.000	0.000	100
	Ban Mai Kasem	0.060	0.159	2.840	69.984	1.100	0.179	4.245	2.467	7.176	1.767	0.000	0.544	9.170	0.000	0.000	0.000	0.000	0.000	0.000	0.214	0.095	0.000	100
	Ban Som	0.080	0.053	2.741	79.447	1.196	0.189	4.145	0.484	3.438	1.878	0.000	0.136	5.950	0.263	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Don Chomphu	0.000	0.000	1.777	42.480	0.740	0.113	5.867	2.234	3.483	5.764	0.000	1.328	34.321	0.115	0.154	0.000	0.000	1.330	0.000	0.000	0.294	0.000	100
	Ban Plo Pla	0.000	0.024	1.543	71.125	1.144	0.182	4.145	1.907	5.288	4.914	0.000	0.265	9.220	0.000	0.000	0.243	0.000	0.000	0.000	0.000	0.000	0.000	100

Table C1 X-Ray Fluorescence (XRF) data of the soil samples (continued).

District	Location	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	Co_3O_4	NiO	ZrO_2	PbO	Cs_2O	CuO	BaO	CeO_2	HfO_2	Total
Khong	Thephalai school	0.080	0.080	0.192	34.425	0.747	0.173	8.221	1.001	21.899	5.553	0.000	0.795	24.375	0.000	0.000	0.000	0.000	2.619	0.000	0.000	0.000	0.000	100
	Ban Wat	0.000	0.000	0.000	78.665	0.000	0.165	2.166	0.227	2.166	2.503	0.053	1.105	12.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Kham school	0.000	0.000	0.000	68.628	0.000	0.073	0.172	1.149	10.819	2.669	0.000	1.086	15.404	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Ta Chan	0.000	0.000	0.000	67.845	0.000	0.093	0	0.903	12.386	2.429	0.088	1.032	15.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Wat Koo Sa Mak Kee school	0.074	0.096	1.584	71.306	1.029	0.083	4.297	0.725	13.189	1.355	0.000	0.152	5.343	0.000	0.000	0.186	0.000	0.581	0.000	0.000	0.000	0.000	100
	Ban Ngiow	0.079	0.073	1.772	85.662	1.072	0.518	1.326	0.465	3.609	1.004	0.000	0.105	3.094	0.000	0.000	0.101	1.12	0.000	0.000	0.000	0.000	0.000	100
	Ban Pho Bit	0.000	0.000	0.000	79.841	0.000	0.379	1.24	0.264	3.817	1.789	0.000	0.116	12.554	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Don Yai	0.000	0.000	5.778	51.111	0.000	0.102	0.463	0.77	10.839	1.667	0.000	1.348	27.922	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Nong Khaem	0.000	0.000	4.535	64.452	0.000	0.131	3.758	1.105	9.474	1.763	0.000	0.423	13.305	0.000	0.000	1.054	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Non Wat	0.144	0.175	1.994	82.863	1.041	0.198	2.825	0.543	6.016	0.811	0.000	0.121	3.225	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.000	100
	Wat Pa Prang Thong	0.153	0.189	3.062	76.925	1.087	0.953	2.871	2.785	5.54	1.263	0.000	0.148	4.792	0.000	0.000	0.232	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Ta Kim	0.217	0.000	1.457	79.011	1.251	0.923	1.765	2.56	4.815	1.834	0.000	0.273	5.784	0.000	0.000	0.11	0.000	0.000	0.000	0.000	0.000	0.000	100
Kham Sakae Saeng	Ban Rim Bung	0.000	0.000	2.159	74.294	1.111	1.294	1.944	2.401	9.547	2.014	0.000	0.122	5.05	0.000	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Nong Hua Fan 1	0.128	0.143	2.865	81.253	0.928	1.041	1.462	1.281	6.59	1.147	0.000	0.219	2.859	0.000	0.000	0.084	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Nong Hua Fan 2	0.000	0.035	1.943	79.338	1.012	1.508	0.753	2.017	9.102	1.398	0.000	0.113	2.69	0.000	0.000	0.091	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Non Ban Na	0.000	0.000	1.864	74.85	1.521	1.613	2.727	2.64	8.736	1.51	0.000	0.124	4.289	0.000	0.000	0.126	0.000	0.000	0.000	0.000	0.000	0.000	100
	Chiwuek temple	0.11	0.178	2.098	78.54	0.963	1.25	1.4	2.736	6.209	0.975	0.000	0.225	5.199	0.000	0.000	0.117	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Nong Jan school	0.000	0.084	2.421	75.832	1.152	1.767	3.369	2.893	5.662	1.176	0.000	0.261	5.304	0.000	0.000	0.079	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Non Jang	0.000	0.000	2.33	81.592	1.015	1.132	0.085	1.14	5.89	2.301	0.000	0.145	4.315	0.000	0.000	0.055	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Sema	0.000	0.057	1.518	75.236	1.017	1.119	2.6	3.315	6.609	2.525	0.000	0.282	5.42	0.000	0.000	0.084	0.000	0.000	0.000	0.000	0.218	0.000	100
	Mueang Nat temple	0.162	0.000	1.827	79.025	1.093	1.214	2.785	2.98	6.023	2.561	0.000	0.156	2.102	0.000	0.000	0.072	0.000	0.000	0.000	0.000	0.000	0.000	100
	Ban Mueang Nat	0.149	0.147	2.357	78.641	1.105	1.287	3.642	1.981	5.527	1.515	0.000	0.136	3.393	0.000	0.000	0.12	0.000	0.000	0.000	0.000	0.000	0.000	100

APPENDIX D

FLAME ATOMIC ABSORPTION SPECTROMETER

(FAAS) DATA

Flame Atomic Absorption Spectrometer data

Table D1 Flame Atomic Absorption Spectrometer data of soil samples according to different seasons.

District	Sub district	UTM E	UTM N	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
					Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Don Yao Yai	232976	1709975	Ban Don Yao Yai	591.00	812.70	97.50	148.70	31.74	32.61	0.369	2.300	957,600.00	1,099,200.00
	Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	351.20	1,403.00	38.43	55.90	48.44	86.51	0.191	0.690	1,711,000.00	16,810,000.00
	Don Yao Yai	235888	1706652	Ban Ra Han Kai	2,515.00	5,246.79	557.00	785.20	35.46	42.14	0.219	2.940	2,279,000.00	3,844,597.00
	Don Yao Yai	231433	1707268	Ban Pa Ta Bang	742.70	1,019.09	214.50	446.10	45.16	67.98	0.183	2.220	7,814,000.00	8,790,044.00
	Samphaniang	240107	1711089	Ban Samphaniang Mai	130.40	877.50	16.40	60.25	32.34	44.62	0.176	2.600	1,244,000.00	2,347,000.00
	Samphaniang	234059	1713514	Ban Na Khu temple	140.70	150.05	15.54	15.70	19.92	34.34	0.290	0.326	101.55	478,800.00
	Samphaniang	235817	1711564	Ban Hua Talad	152.13	235.70	626.00	792.45	49.76	55.42	1.920	2.010	5,021,790.18	5,543,872.00
	Samphaniang	237465	1711266	Ban Fang school	1,791.50	2,577.00	453.50	865.00	30.29	47.48	0.168	2.600	8,350,092.31	8,926,543.00
	Wang Hin	235813	1712805	Ban Toie	155.30	763.80	22.30	78.80	28.46	35.40	2.400	2.520	196.67	1,189,314.69
	Wang Hin	236232	1714263	Ban Toie temple	384.25	1,903.00	48.80	1,106.00	220.30	289.70	2.879	3.900	2,294.33	9,003,314.69
	Wang Hin	239537	1713359	Ban Hin Tang	305.80	681.20	51.60	168.60	33.71	41.46	0.257	0.323	1,658.33	3,638,040.18
	Non Ta Then	231234	1710843	Ban Non Ta Then	100.40	975.00	56.40	274.40	10.22	26.49	0.454	0.512	4,521.00	536,092.31
	Non Ta Then	228668	1709073	Ban Non Ta Then temple	1,761.00	121.56	3.98	174.33	54.60	95.06	1.251	0.216	341.90	3,687,459.82
	Non Ta Then	232310	1711124	Ban Non Noi	1,103.00	389.60	54.80	103.00	17.26	35.30	0.124	0.219	4,306.00	3,909,848.21
Non Thai	Dan Chak	186902	1679575	Ban Dan Chak	225.30	397.55	52.70	96.60	19.90	27.90	0.493	0.500	681,400.00	1,200,314.69
	Dan Chak	188274	1678720	Ban Dan Chak temple	134.34	769.90	71.90	2,085.00	13.45	154.85	0.334	0.379	3,603.00	14,126,104.87
	Non Thai	184673	1682935	Sai Mit Non Thai school	950.00	1,227.00	688.00	789.00	48.48	58.10	0.252	0.275	1,476,000.00	7,810,000.00
	Sam Rong	178417	1673084	Ban Song Tham	72.35	1,350.50	25.10	462.00	13.00	23.82	0.250	0.280	549.00	5,122,790.18
	Sam Rong	178814	1671006	Ban Nong Krad	113.28	1,082.00	223.00	1,154.00	28.34	80.45	0.389	0.437	754,600.00	9,143,314.69
Non Sung	Mai	209858	1675501	Ban Jan Dum 1	251.90	1,040.00	37.30	276.50	12.62	64.72	0.251	0.308	763.20	8,020,092.31
	Mai	210482	1679135	Ban Jan Dum 2	154.40	1,872.00	57.90	495.00	19.14	33.36	0.061	0.459	1,251,000.00	2,562,036.00
	Lum Khao	210114	1680537	Ban Chad	402.75	1,866.50	65.20	277.00	23.11	25.43	0.145	0.283	1,008,000.00	5,064,000.00
	Bing	210826	1674312	Ban Bing	1,373.50	1,881.00	233.00	408.00	13.26	13.43	1.088	1.470	2,683,500.00	5,051,790.18
	Bing	213043	1674734	Ban Pet	251.40	6,086.00	169.50	412.00	30.58	32.60	0.200	0.368	863,500.00	7,534,000.00
	Than Prasat	218707	1688319	Ban Mai Kasem	952.50	2,714.00	128.67	439.00	26.99	41.86	0.082	0.345	3,503,059.00	4,019,848.21
	Don Chomphu	214228	1680448	Ban Som	346.40	434.95	57.30	551.00	22.62	25.51	0.098	0.325	1,051,500.00	2,927,000.00
	Don Chomphu	214406	1677123	Ban Don Chomphu	54.68	339.40	10.10	71.10	11.56	17.77	0.315	0.421	1,019,500.00	5,022,350.18
	Don Chomphu	214590	1678757	Ban Plo Pla	443.00	503.00	69.70	99.10	11.90	30.96	0.176	0.245	1,559,000.00	2,125,000.00

Table D1 (Continued) Flame Atomic Absorption Spectrometer data of soil samples according to different seasons.

District	Sub district	UTM E	UTM N	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
					Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Khong	Thephalai	228122	1702977	Thephalai school	158.94	616	8.82	10.4	16.64	19.86	0.036	0.263	1,066.00	5,020,980.18
	Thephalai	223707	1699278	Ban Wat	236.8	1,607.00	68.1	151.5	11.85	21.14	0.012	0.507	1,145,500.00	2,279,000.00
	Kham Sombun	222077	1700185	Ban Kham school	629	826.5	184.8	200	36.95	42.4	0.134	0.319	1,064,000.00	1,980,000.00
	Ta Chan	220572	1694233	Ban Ta Chan	79.89	171.38	7.73	22.15	4.52	5.12	0.449	0.79	303.5	480,800.00
	Khu Khat	222455	1706779	Wat Koo Sa Mak Kee school	59.39	67.62	37.05	54.79	103.74	110.5	0.21	0.33	5,874,451.00	7,947,000.00
	Khu Khat	225005	1708358	Ban Ngiow	273.8	562.81	79.6	82.34	22.58	30.77	0.044	0.156	893,471.00	1,252,000.00
	Khu Khat	219948	1706120	Ban Pho Bit	665	3,604.50	44.2	346	13.9	42.32	0.31	0.53	596,000.00	9,004,000.00
	Mueang Khong	212267	1703423	Ban Don Yai	525.6	1,341.50	78.25	226.4	43.11	118.38	0.047	0.239	3,648.00	474,000.00
	Mueang Khong	211910	1708271	Ban Nong Khaem	908.5	1,147.00	522	619	77.53	110.64	0.012	0.592	2,553,000.00	5,071,000.00
	Mueang Khong	211224	1708348	Ban Non Wat	1,156.00	1,621.00	342	585	52.36	69.52	0.031	0.315	768,000.00	5,051,790.18
	Ban Prang	187597	1715276	Wat Pa Prang Thong	358.7	1,435.00	412	574	62.43	79.5	0.015	0.342	1,763,541.00	5,003,700.00
	Nong Bua	192530	1717177	Ban Ta Kim	115.4	1,593.00	48.1	760	12.37	50.45	0.42	0.783	110.54	3,652,000.00
Kham Sakae Saeng	Mueang Kaset	206618	1702113	Ban Rim Bung	536.4	614.33	138.5	168.53	25.39	48.55	0.069	0.098	847,000.00	1,435,189.00
	Nong Hua Fan	206028	1702416	Ban Nong Hua Fan 1	160.78	210.86	27.17	108.09	7.24	12.62	0.087	0.096	480,000.00	654,723.00
	Nong Hua Fan	203192	1704728	Ban Nong Hua Fan 2	452.67	561.47	718	752.17	21.29	35.98	0.073	0.089	857,600.00	1,021,359.00
	Nong Hua Fan	202892	1705899	Ban Non Ban Na	310.1	1,640.00	92.2	795	21.02	61.69	0.304	0.56	1,561,000.00	2,110,000.00
	Chiwuek	200940	1709601	Chiwuek temple	68.42	104.77	5.87	8.62	3.73	5.87	0.107	0.175	485,200.00	784,535.00
	Kham Sakaesaeng	202822	1706078	Ban Nong Jan school	195	215.92	56.1	62.14	34.63	45.8	0.033	0.098	2,673,922.00	4,012,000.00
	Kham Sakaesaeng	196954	1703106	Ban Non Jang	164.22	569.1	21.8	41.32	6.32	8.76	0.038	0.077	857,600.00	1,509,348.00
	Mueang Nat	197182	1703411	Ban Sema	188.45	1,796.00	356	435.8	33.3	89.63	0.477	0.576	548,761.00	1,352,000.00
	Mueang Nat	195905	1700730	Mueang Nat temple	121.4	989.4	174.33	377.1	77.2	114.89	0.432	0.544	519,342.00	1,372,000.00
	Mueang Nat	191176	1698356	Ban Mueang Nat	25.31	914.1	18.3	176	14.33	263	0.295	0.354	212.7	8,550,000.00

Table D2 Flame Atomic Absorption Spectrometer of groundwater samples according to different seasons.

District	Sub district	UTM E	UTM N	Well no.	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
						Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Non Daeng	238141	1706668	5705D031	Non Daeng Municipal school	102.00	708.00	37.90	169.80	11.66	102.48	0.13	0.56	576.20	2,039,000.00
	Non Daeng	238343	1705364	5405B007	Phu Wittaya school	25.45	47.01	7.64	13.24	2.27	7.48	0.11	0.53	135.15	1,274.00
Non Thai	Banlang	170357	1688964		Ban Muang Kao 2	6.09	7.42	9.18	10.24	4.38	5.68	0.63	0.71	278.30	354.98
	Makha	187792	1689952	MG1571	Nong Doom health promoting hospital	11.83	28.84	7.36	26.98	3.79	5.16	0.20	0.30	234.90	744.30
Non Sung	Than Prasat	222250	1687690	-	Ban Talad Kae	12.14	31.42	9.24	32.92	4.12	5.54	0.51	0.75	293.50	815.40
	Tanot	206821	1671468	D0516	Ban Non Makok	28.62	35.24	8.01	8.43	3.56	4.19	0.10	0.52	422.00	581.00
Khong	Nong Bua	195999	1717793	MG679	Ban Nong Sakae school	6.40	99.36	15.48	48.40	3.81	4.07	0.11	0.54	159.55	369.30
	Nong Bua	192508	1717165	5505G052	Ban Ta Kim	123.80	134.90	26.12	41.40	12.05	12.88	9.76	9.79	389.80	765.20
Kham Sakae Saeng	Non Mueang	189356	1706970	MY337	Ban Khum Muang	21.92	98.72	18.54	31.98	8.17	8.65	0.15	0.43	241.60	425.00
	Nong Hua Fan	207082	1705864	MG1637	Ban Jod school	15.53	168.50	31.90	64.80	5.89	6.00	0.13	0.15	216.85	516.40

Table D3 Flame Atomic Absorption Spectrometer of surface water samples according to different seasons.

District	Sub district	UTM E	UTM N	Location	Calcium		Magnesium		Potassium		Iron		Sodium	
					Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Non Daeng	Non Daeng	231234	1710843	Non Ta Then reservoir	76.34	101.70	14.52	23.12	7.03	7.15	0.22	0.43	539.60	1,049.50
	Don Yao Yai	233356	1709849	Ban Don Yao Yai health promoting hospital	33.81	59.81	1.90	2.18	6.42	6.76	0.53	0.62	133.20	12,391.43
Non Thai	Dan Chak	1678720	188274	Ban Dan Chak reservoir	82.80	86.08	5.50	24.06	6.67	8.01	0.23	0.40	488.60	1,033.00
	Non Thai	183315	1680970	Don Bot temple reservoir	108.20	114.67	15.70	19.54	4.41	4.79	0.17	0.48	1,172.50	3,355.71
Non Sung	Bing	210826	1674312	Bing reservoir	17.26	61.54	8.72	17.60	5.59	5.78	0.53	5.66	515.60	4,361.43
	Don Chomphu	215493	1682185	Lum Chiang Krai river (Ban Som)	33.91	36.21	7.50	16.16	4.72	7.82	0.41	8.79	295.50	892.60
Khong	Khu Khat	222394	1706686	Kud Vien reservoir	19.50	29.84	4.78	5.50	8.58	10.49	0.43	0.48	103.04	110.92
	Mueang Khong	211620	1702627	Bueng Don Yai reservoir	31.81	34.83	11.20	14.78	6.52	7.48	0.22	0.30	141.50	249.80
	Kham Sombun	221489	1700984	Non Si Fun reservoir	23.62	30.12	7.71	9.12	6.35	7.78	0.63	0.80	4.79	8.45
Kham Sakae Saeng	Kham Sakae Saeng	196920	1694693	Ban Bu La Kro reservoir	75.38	84.60	17.32	27.54	14.16	15.22	0.17	0.37	244.50	472.40
	Kham Sakae Saeng	195785	1701679	Ban Yakha Non Jang school reservoir	429.80	593.80	68.60	243.00	14.93	27.48	0.21	0.47	956.60	1,139.20
	Kham Sakae Saeng	197128	1703284	Non Lan canal	25.51	40.97	16.36	24.80	2.14	3.15	0.07	1.16	522.20	549.60

APPENDIX E

PUBLICATION

List of publication

Thongwat, W., and Terakulsatit, B., (2019). Using GIS and map data for the analysis of the relationship between soil and groundwater quality at saline soil area of Kham Sakaesaeng District, Nakhon Ratchasima, Thailand. **In Proceedings of WASET the 21st international research conference proceedings**, 07-08 January 2019, Tokyo, Japan, pp. 99-106.

Tokyo Japan Jan 07-08, 2019, 21 (1) Part I

Using GIS and Map Data for the Analysis of the Relationship between Soil and Groundwater Quality at Saline Soil Area of Kham Sakaesaeng District, Nakhon Ratchasima, Thailand

W. Thongwat, B. Terakulsatit

***Abstract*—The study area is Kham Sakaesaeng District in Nakhon Ratchasima Province, the south section of Northeastern Thailand, located in the Lower Khorat-Ubol Basin. This region is the one of saline soil area, located in a dry plateau and regularly experience standing with periods of floods and alternating with periods of drought. Especially, the drought in the summer season causes the major saline soil and saline water problems of this region. The general cause of dry land salting resulted from salting on irrigated land, and an excess of water leading to the rising water table in the aquifer. The purpose of this study is to determine the relationship of physical and chemical properties between the soil and groundwater. The soil and groundwater samples were collected in both rainy and summer seasons. The content of pH, electrical conductivity (EC), total dissolved solids (TDS), chloride and salinity were investigated. The experimental result of soil and groundwater samples show the slightly pH less than 7, EC (186 to 8,156 us/cm and 960 to 10,712 us/cm), TDS (93 to 3,940 ppm and 480 to 5,356 ppm), chloride content (45.58 to 4,177,015 mg/l and 227.90 to 9,216,736 mg/l), and salinity (0.07 to 4.82 ppt and 0.24 to 14.46 ppt) in the rainy and summer seasons, respectively. The distribution of chloride content and salinity content were interpolated and displayed as a map by using ArcMap 10.3 program, according to the season. The result of saline soil and brined groundwater in the study area were related to the low-lying topography, drought area, and salt-source exposure. Especially, the Rock Salt Member of Maha Sarakham Formation was exposed or lies near the ground surface in this study area. During the rainy season, salt was eroded or weathered from the salt-source rock formation and transported by surface flow or leached into the groundwater. In the dry season, the ground surface is dry enough resulting salt precipitates from the brined surface water or rises from the brined groundwater influencing the increasing content of chloride and salinity in the ground surface and groundwater.**

***Keywords*—Environmental geology, soil salinity, geochemistry, groundwater hydrology.**

I. Introduction

The salinity of the soil is naturally occurred by rock salts, dissolved and dispersed in the lowland and the groundwater table is very shallow by the groundwater. The deforestation is another serious cause of the saline soil crisis. When chloride concentration in soil is high, that will affect the growth of plants. The plants were damaged by disrupting their intake of water and interfering with the absorption of nutrients, caused by an excessive salt in the soil [1]. Generally, groundwater contaminants occurred when flow through the sediment. The ions in sediment are dissolved and accumulated in the water, may later be found high concentrations. The ions dissolved in groundwater are both occurred by human activities and natural. The human activities are effluent from private, municipal septic systems, and some agricultural chemicals. The natural sources include rock-water interactions, saline seeps, and minor atmospheric contributions. Especially, summer period found salt exposed on the ground in several places [2].

The saline groundwater is a cause of saline soil in the Northeast of Thailand. Drought, the saline groundwater was seeping to the surface by capillary movement, then crystallize on the ground [3]. It has recently been reported that about 29% of the present arable land is affected by salinity [4]. Kham Sakaesaeng District is in Nakhon Ratchasima Province, located in the Lower Khorat-Ubol Basin. This region is the one of saline soil areas, which affect the salinity soil and groundwater. The objective of this study is to determine the relationship of physical and chemical properties between the soil and groundwater, focusing the investigations into the content of chloride and salinity, and create the map the distribution of saline soil and groundwater in study area according to the season.

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II. General Geology and Hydrogeology of Khorat-Ubon Basin

The Khorat Plateau of northeastern Thailand contains a large evaporate basin of Cretaceous age. It is divided into a northern (Udon-Sakon Nakhon) Basin and a southern (Khorat-Ubol) Basin. The evaporate beds are included in the Maha Sarakham Formation [5]. A major source of salinity, the Rock Salt of the Maha Sarakham Formation is exposed or lies close to the surface [6]. This formation divided into six units from bottom to top as follows: the lower salt, the lower clastics, the middle salts, the middle clastics, the upper salt and the upper clastic, shown in Fig. 1 [7].

The Khorat Plateau Basin is defined by the large area of Mesozoic era (mainly Cretaceous) continental sedimentary rocks of the Khorat Group. Stratigraphy of the Khorat-Ubol Basin was shown in Fig. 2. The lower Khorat units consist of

Figure E.1 The author’s publication in proceedings of WASET: The 21st international research conference proceedings (p. 99).

Huai Hin Lat Formation, Nam Phong Formation, Phu Kradung Formation, Phra Wihan Formation, Sao Khua Formation, Phu Phan Formation, and Khok Kruat Formation. The upper Khorat Units consists of Maha Sarakham Formation and Phu Tok Formation [8].

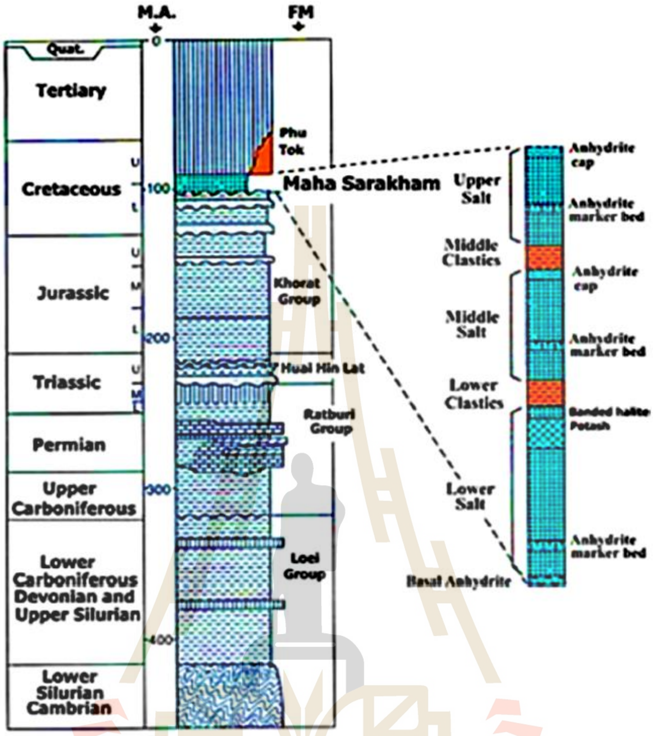


Fig. 1 Lithostratigraphy and subdivisions of the Khorat Group and the Maha Sarakham Formation (modified after [7])

Hydrogeology characteristics of Nakhon Ratchasima Province are mostly underlain by consolidated rocks, composed of sandstone, shale, and siltstone of Mesozoic age [10]. The aquifer can be divided into two types as follows:

1. The unconsolidated aquifer is found in two deposits: Alluvial deposits and High Terrace and Colluvium deposits.

- Alluvial deposits: aquifers in these deposits occur along the Mun and Lam Takhong Rivers. The aquifer is formed as a narrow and elongate strip following east-west directions. Groundwater is stored in sand and gravel layers at a depth between 10 and 30 m. The layers were built up by meandering streams. They mainly consist of sand and gravel which is interbedded with thin layers of clay. However, groundwater in this layer hydraulically interconnected.
- High terrace and colluvium deposits: These deposits form aquifer in the hilly area south of Nakhon Ratchasima Province and in the floodplain area where they are overlain by Alluvial deposits. Groundwater is commonly found in sand and gravel at two distinct depth intervals: 20-40 m and 50-70 m below ground surface. A layer of fine-grained material separates the two sand and gravel layers with a thickness of about 10 m.

2. The consolidated aquifer is recognized in eight formations.

- Phu Tok Formation: It is not well cemented and slightly soft when compared to the underlying formations. It mainly comprises of claystone, siltstone, and sandstone. The formation is competent and usually forms a good aquifer. Groundwater in this formation is poor, due to high sodium chloride content.
- Maha Sarakham Formation: Its most shallow occurrence is found at depth of around 80 to 100 m below ground surface. From the seismic section profile, the upper surface of the rock salt is generally smooth and gently

Figure E.2 The author’s publication in proceedings of WASET: The 21[st] international research conference proceedings (p. 100).

inclined to the North-East. Principally, the formation acts as an aquitard due to the non-existing primary porosity. Groundwater can only be trapped in the formation where it may be in contact with overlying porous rock units. Most salt mines pump brine water from such aquifers.

- Khok Kruat Formation: Groundwater mainly occurs in spaces of fractures and bedding planes of sandstone, shale, and siltstone. Groundwater quality in this formation is generally good. However, saltwater can be found in the areas where the rock is in contact with the Maha Sarakham Formation.
- Phu Phan Formation: The unit is characterized by massive coarse quartz sandstone with some conglomerate. The unit that varies from 100 to 400 m in thickness was deposited forms nearly flat top hills to undulating terrain. Yield ranges of 1 to 10 m^3/h can be expected from drilled well penetrated to the fractured zone of the aquifer. Groundwater is generally good quality occasionally high iron contents. This formation is not flowing artesian although several flowing wells have been drilled.
- Pha Wihan Formation: This unit that varies from 50 to 297 m in thickness consists of a massive highly resistant white to pink, thick bedded, well-sorted quartz sandstone, with thin beds of laminated red siltstone. Groundwater is good quality.
- Sao Khua Formation: This unit is composed of sandstone and siltstone, varying in thickness from 400 to 720 m. Yield from many boreholes in Sao Khua aquifer range from 5 to 10 m^3/h with exceptionally good quality water.
- Phu Kradung Formation: This unit has an average thickness of about 972 m outcrop and sub outcrop around the Khorat Plateau. It is composed of shale, siltstone, sandstone, and conglomerate. Yield ranges of 10 to 40 m^3/h better than Phu Phan and Pha Wihan Formations. Groundwater quality in term of TDS is generally less than 50 mg/l.
- Nam Phong Formation: Consists of a sequence of siltstone, sandstone, and conglomerates. The total thickness of the formation is 1,456 m. The aquifer rests on the Pre- Khorat erosional surface west of the northern part of the Khorat Plateau.

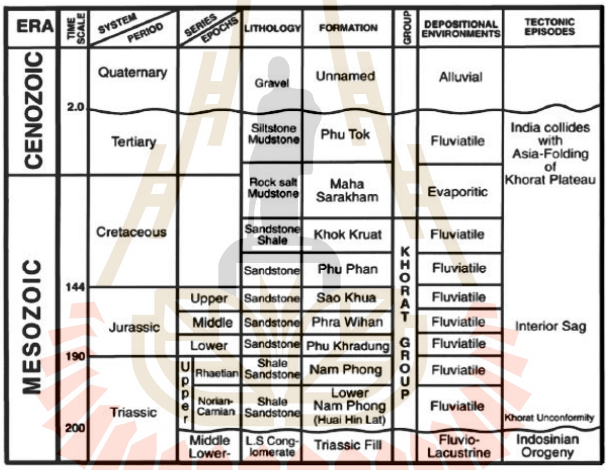


Fig. 2 General Stratigraphy of the Udon-Sakon Nakhon Basin and the Khorat-Ubol Basin [9]

The main cause of saline soil is caused by rock salt (Maha Sarakham Formation), dissolved and moved by groundwater. The salt moves rapidly to the surface by a fault in a salt dome, as the pathway for upward movement of the saline groundwater. the groundwater dissolves the salt domes is a catalyst to the saline soil crisis. The gravity is the capillary force which pulls the brine up to the surface, then the water evaporates from the brine and salt crystallizes on the topsoil [4].

III. Study Area

The Nakhon Ratchasima Province is located in northeastern Thailand. The provincial area covers approximately 20,493.964 km^2. The provincial average climate, the temperature is 27.4 °C, the relative humidity is 71% and the average annual rainfall is 1,028.1 mm.

Kham Sakaesaeng District, Nakhon Ratchasima Province is the study area (Fig. 3) that consists of seven subdistricts including Non-Mueang, Mueang Kaset, Nong Hua Fan, Chiwuek, Pha-Ngat, Kham Sakaesaeng, and Mueang Nat. Generally, the usage of land in this area is dominant and is restricted to rice, cassava, and sugar cane field crops and forest. However, the utilization of the area is not sufficiently effective due to the affected by salt accumulation in soil and

Figure E.3 The author’s publication in proceedings of WASET: The 21st international research conference proceedings (p. 101).

groundwater.

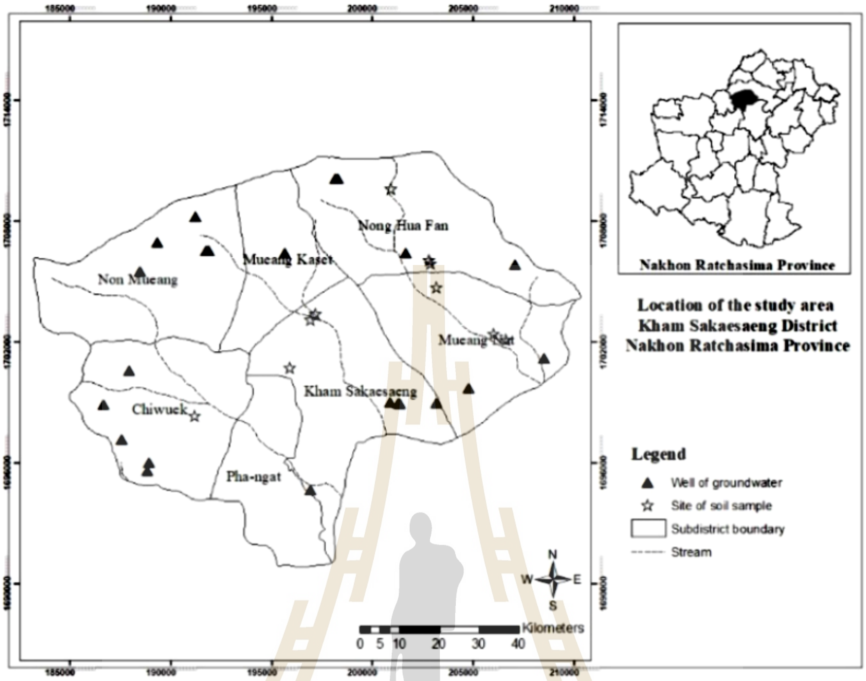


Fig. 3 Location of the study area, Kham Sakaesaeng District, Nakhon Ratchasima Province

IV. Methodology

A variety of secondary data was obtained from various regional and local government offices. The data included land use maps from the Land Development Department, annual rainfall data from the Meteorological Department, the quality of surface water data from the Pollution Control Department, and borehole log and groundwater data from the Groundwater Resource Department. All of these datasets were compiled together to locate appropriate soil, groundwater, and surface water sampling locations. The soil and groundwater samples were collected during the rainy season on October 2017, and the summer season on May 2018.

A. Soil Samples

In the study area, there are seven soil sampling sites, consisting of Mueang Kaset Subdistrict (Ban Rim Bung), Nong Hua Fan Subdistrict (Ban Nong Hua Fan and Ban Non Ban Na), Chiwuek Subdistrict (Ban Chiwuek), Kham Sakaesaeng Subdistrict (Ban Non Jan, and Band Non Jang), and Mueang Nat Subdistrict (Ban Sema, Ban Mueang Nat, and Ban Mueang Nat). These locations of soil sampling site were shown in Table I. The soil samples were collected at a varying depth from 15-30 cm below the ground surface, then kept in plastic bags and sent to the laboratory. The determination of soil properties included pH, EC, TDS, chloride content, and salinity content. The measurement of soil samples on a soil solution of three parts of the soil and one part of water extract then left the soil solution for two days [11], then extract the water from the soil solution by the filter press. The measurement of EC, TDS, and salinity has used the probes into the soil solution directly. The chloride content was analyzed by titration of the soil solution.

B. Groundwater Samples

There are 22 groundwater sampling wells, consisting of Non Mueang Subdistrict (Ban Taluk Hin, Ban Non Mueang, Ban Ngio, Ban Khum Mueang, and Ban Sa Kruat), Mueang Kaset Subdistrict (Ban Khu Mueang), Nong Hua Fan Subdistrict (Ban Non Maklue, Ban Non Maklue, Ban Jod, and Chomchon Nong Hua), Chiwuek Subdistrict (Ban Hua Bung, Ban Nong Pho, and Ban Non Phak Chi), Kham Sakaesaeng Subdistrict (Ban Nook, Ban Namab, and Ban Bu La Kro), and Mueang Nat Subdistrict (Ban Sema, and Ban Nong Pho Namab). These locations of groundwater well were shown in Table I. The groundwater samples were collected after pumped out for five minutes. The groundwater and surface

Figure E.4 The author's publication in proceedings of WASET: The 21st international research conference proceedings (p. 102).

water samples were measured on the sites for pH, EC, TDS, and salinity content. The chloride content in the water samples was analyzed in the laboratory by the titration.

C. Interpolate

The interpolated of soil samples were analyzed for a relationship with the interpolated of groundwater. All the parameter values were input into ArcMap 10.3 program. Then, the maps presented the results of the chloride content and salinity content in soil and groundwater.

V. Results and Discussion

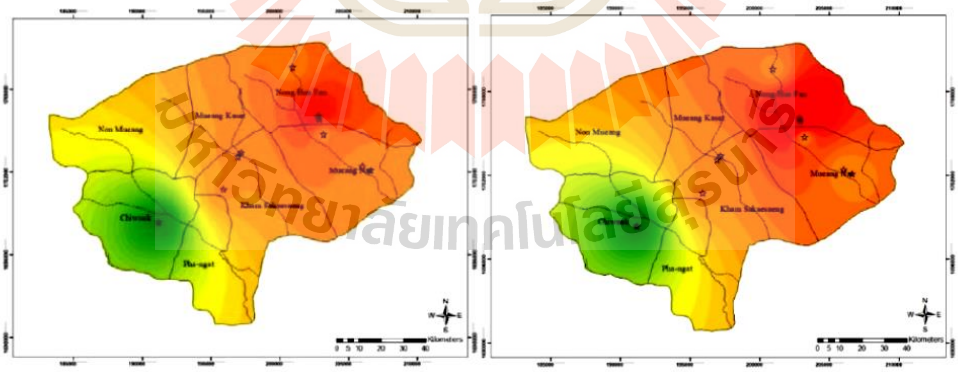
The result of the relationship between the quality of saline soil and groundwater according to the season was shown in Table I, Figs. 4 and 5. The main components of the soil in the study area are sand, clay, and silt. The soil sample has 6.14-6.91 pH. The EC of sand is lower than 150 µs/cm indicating the non-saline, which has negligible effect on plant growth. However, the EC is higher than 300 µs/cm indicating the saline, which is harmful to plant growth. The EC and TDS of soil sample are moderately low in the rainy season and high in the summer season, respectively. At Ban Nong Hua Fan 1 site represented the highest values in the summer season as 10,712 µs/cm of EC, and 5,356 ppm of TDS, respectively. The high content of EC and TDS in the soil sample related to the chloride and salinity contents (Table I).

The groundwater has 6.13-7.00 pH showing a positive correlation with the pH of the soil. The TDS of groundwater depends on the season (Table I), representing the lower than 1,000 ppm that indicates the fresh water (TDS as 0-1,000 ppm) in the rainy season. The summer season has 1,000-4,300 ppm of TDS, which indicates the brackish water (TDS as 1,000-10,000 ppm) [12].

Generally, the salinity of the fresh or non-saline water is less than 0.5 ppt. The brackish water is range from 0.5-35 ppt of salinity, and the salinity is higher than 35 ppt indicates a very saline water or seawater. The salinity of groundwater in the study area has 0.07-4.32 ppt in the rainy, and 0.24-4.38 ppt in the summer season indicating the brackish water.

The content of salinity, chloride, EC, and TDS in the groundwater also are similarly correlated with the soil. The high contents of salinity and chloride were related to the low-topography indicate to the groundwater flow direction led to the accumulation of saline water in the low attitude and the groundwater was also near to the soil surface. In the rainy season, the groundwater quality represents the fresh water, then turn to the brackish and saline water in the summer season. For example, the Chumchon Nong Hua Fan School site is the highest content as 4.38 ppt of salinity, 7,305.28 mg/l of chloride content, 4,297 ppm of TDS, and 8,594 µs/cm in the period of drought. The groundwater in this site is not suitable for consumption and agriculture due to the groundwater turn to saline water.

Figs. 4 and 5 exhibit the distribution of chloride and salinity contents that interpolated and displayed as a map by using ArcMap 10.3 program according to the season. The results of saline soil and saline groundwater in the study area were related to the low-lying topography (MSL less than 200 m), drought area, and salt-source exposure. The study area has the rock salt member of Maha Sarakham Formation adjacent to the soil surface and in some areas exposed to a salt layer [3]. The shallow saline groundwater has been found in Kham Sakaesaeng District and caused by rock salt that represented by the electrical survey [13], [14]. The saline soil area is easy to observe from the crystallized of salt are covered on topsoil. The eroding and weathering of salt from the source rock salt and movement of salt usually occurs in the rainy season. The movement of salt is caused by the flow of surface water and leached into the groundwater. Drought, the topsoil is dry enough is dry enough to result in salt crystallizes and rises from the saline groundwater, that influences the increasing content of chloride and salinity in the ground surface and groundwater. The problem was caused by groundwater dissolution of salts and accumulating them at the soil surface, the shallow saline groundwater is a factor that can influence topsoil salinity [15].



(a) (b)

Figure E.5 The author’s publication in proceedings of WASET: The 21st international research conference proceedings (p. 103).

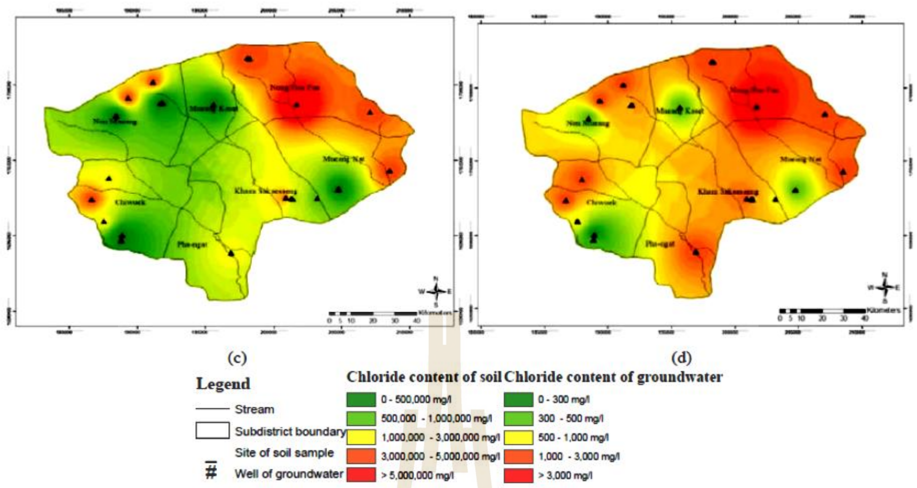


Fig. 4 Chloride content map at (a) soil sample in the rainy season, (b) soil sample in summer season, (c) groundwater sample in the rainy season, and (d) groundwater sample in the summer season

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF SOIL AND GROUNDWATER SAMPLES

Samples	Location	Mean Sea Level (MSL, m)	pH		EC (us/cm)		TDS (ppm)		Salinity (ppt)		Cl- (mg/l)	
			Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
	Ban Rim Bung	190	6.67	6.59	226	2,104	113	1,052	0.10	0.51	1,050,809.26	1386308.61
	Ban Nong Hua Fan 1	186	6.35	6.67	7,434	10,712	3,717	5,356	4.82	14.46	2,911,881.09	9,216,736.66
	Ban Nong Hua Fan 2	187	6.26	6.55	6,380	9,436	3,190	4,718	4.15	5.74	4,177,916.35	5,532,574.07
	Ban Non Ban Na	201	6.63	6.84	256	2,580	128	1,290	0.13	1.01	1,114,111.03	1,709,147.41
Soil	Chiwuek Temple	192	6.64	6.72	1,658	10,306	829	5,153	0.08	0.49	215,225.99	745,061.48
	Ban Nong Jan School	186	6.46	6.14	5,836	6,040	2,918	3,020	2.43	4.03	2,373,816.11	4,025,992.11
	Ban Non Jang	194	6.28	6.91	3,374	5,894	1,687	2,947	1.65	3.94	2,253,542.76	3,962,690.35
	Ban Sema	174	6.35	6.76	964	3,068	482	1,534	0.50	0.87	1,310,346.49	1,892,722.71
	Mueang Nat Temple	188	6.32	6.53	2,480	5,626	1,240	2,813	1.39	2.56	1,493,921.60	2,677,920.74
	Ban Mueang Nat	177	6.39	6.48	186	1,004	93	502	0.08	0.72	1,057,139.44	1,569,883.72
	Ban Non Mueang School	207	6.94	6.51	1,046	1,670	515	835	0.51	0.53	215.73	1,095.37
	Ban Taluk Hin	221	6.64	6.08	1,020	1,034	490	517	0.24	0.55	227.89	414.00
	Ban Ngio School	212	6.57	6.14	2,092	2,114	1,069	1,074	1.06	1.60	1,124.24	1,968.94
	Ban Khum Muang	214	6.38	6.8	1,826	1,856	823	988	0.89	0.90	1,051.32	1,076.16
	Ban Sa Kruat	206	6.55	6.84	1,080	1,432	568	716	0.53	0.56	258.27	683.66
	Ban Khu Mueang School	200	6.88	6.52	604	1,086	302	537	0.36	0.59	133.69	437.54
	Chumchon Nong Hua Fan School	184	6.15	6.47	8,156	8,594	3,940	4,297	4.32	4.38	6,168.12	7,305.28
	Ban Non Makluea Temple	213	6.58	6.21	2,870	3,438	1,435	1,719	1.35	1.43	1,815.49	2,175.90
	Ban Non Makluea School	212	6.85	6.19	2,248	2,890	1,247	1,487	1.36	1.48	1,952.23	2,311.79
	Ban Jod School	198	6.43	6.66	2,286	3,996	1,166	1,998	1.28	1.45	1,739.53	2,310.77
	Chiwuek 1	199	6.68	6.08	738	960	368	480	0.36	0.49	240.04	358.54
Groundwater	Chiwuek 2	207	6.13	6.85	1,989	2,248	995	1,247	1.17	1.39	832.54	2,060.40
	Ban Hua Bung	200	6.48	6.64	284	1,020	137	490	0.07	0.24	45.58	227.90
	Ban Nong Pho	207	6.5	6.57	1,278	2,092	637	1,069	0.64	0.81	525.66	948.01
	Ban Non Phak Chi School	209	6.18	6.19	2,228	2,890	1,150	1,487	1.19	1.43	1,450.88	2,217.99
	Ban Nook 1	185	6.78	6.22	960	1,178	498	587	0.51	0.99	595.54	1,266.29
	Ban Nook 2	182	6.08	6.13	960	4,002	480	2,050	0.49	0.88	376.77	805.20
	Ban Nook School	182	6.78	6.19	2,160	3,204	1,082	1,602	1.15	1.31	1,777.51	1,190.33
	Ban Namab	184	6.52	7	1,086	1,200	537	600	0.29	0.59	443.62	734.55
	Ban Bu La Kro	177	6.53	6.7	1,682	2,894	842	1,447	0.88	0.97	786.97	1,253.37
	Ban Sema School	176	6.07	6.98	2,532	2,998	1,266	1,494	1.19	1.42	1,815.49	1,975.01
	Ban Nong Pho Namab School	182	6.36	6.52	366	1,086	184	537	0.25	0.61	237.00	492.48

Remarks: The blue highlights are the brackish soil and groundwater, and pink highlights are the saline soil and groundwater.

Figure E.6 The author's publication in proceedings of WASET: The 21st international research conference proceedings (p. 104).

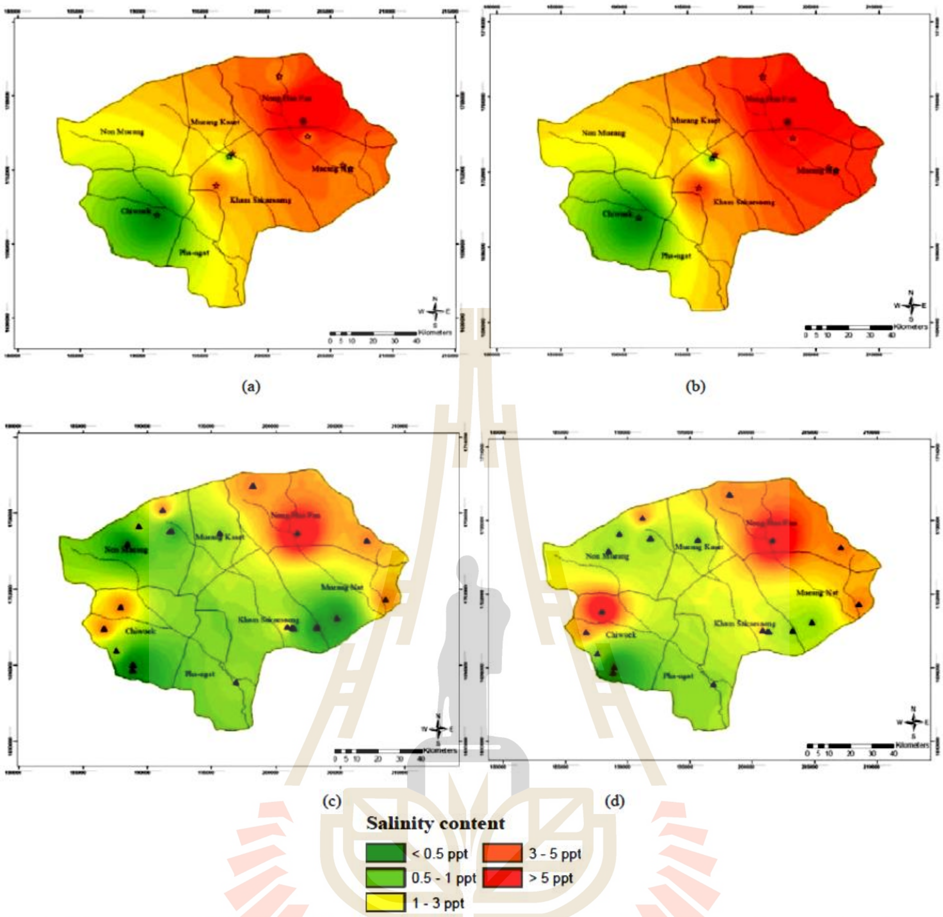


Fig. 5 Salinity content map at (a) soil sample in the rainy season, (b) soil sample in summer season, (c) groundwater sample in the rainy season, and (d) groundwater sample in the summer season

VI. Conclusion

The quality of soil and groundwater was investigated in both the rainy season (October 2017) and the summer season (May 2018). The salt affected study areas in the dry season, which influenced by the salinity of groundwater and the topsoil underlay by Maha Sarakham Formation. The salinity of soil occurred in the same direction as the groundwater flow, which represented in the low-topography (MSL less than 200 m). Some location is a high-elevated area (MSL about 200 to 300 m), the groundwater level is not near the surface causing to the non-saline area. The groundwater is an important pathway that can bring a salinity from deep aquifers to the soil and surface water. The drought period, the groundwater dissolved the salt rock of Maha Sarakham Formation and the salt move upward from the source to surface by groundwater, which makes to the exceed evaporation and precipitation causing to the high salinity content in the topsoil. The usage of GIS can be mapping the distribution of the salinity and chloride contents in both soil and groundwater and classified the non-saline and saline area according to the season. It can be concluded that the salinity soil relates to the season and the flow direction of groundwater, which indicated by the gently increased of chloride and salinity contents in groundwater.

Figure E.7 The author's publication in proceedings of WASET: The 21st international research conference proceedings (p. 105).

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Figure E.8 The author's publication in proceedings of WASET: The 21st international research conference proceedings (p. 106).

BIOGRAPHY

Miss Wannida Thongwat was born on the 5th of December 1993 in Bangkok, Thailand. She earned her high school diploma in science-math program from St. Marry School in 2010 and Bachelor's Degree in Engineering (Geotechnology) from Suranaree University of Technology (SUT) in 2014. After graduation, she continued with her master's degree of Engineering Program in Civil, Transportation and Geo-resources Engineering, Petroleum Engineering Major, Department of Geotechnology, Institute of Engineering, Suranaree University of Technology (SUT). During 2016-2018, she had been